$12.50
KD

International Library of Technology
351B

TOOLMAKING

219 Illustrations

Prepared Under Supervision of
A. B. CLEMENS
DIRECTOR, MECHANICAL SCHOOLS
INTERNATIONAL CORRESPONDENCE SCHOOLS

GAUGES AND GAUGE MAKING
JIGS AND FIXTURES
DIES AND DIE MAKING
HARDENING AND TEMPERING
HEAT TREATMENT OF LOW-CARBON STEEL

Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
1926

Printed in U. S. A.

Press of
International Textbook Company
Scranton, Pa.
351B

89199

PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed.

INTERNATIONAL TEXTBOOK COMPANY

B

CONTENTS

NOTE.—This volume is made up of a number of separate Sections, the page numbers of which usually begin with 1. To enable the reader to distinguish between the different Sections, each one is designated by a number preceded by a Section mark (§), which appears at the top of each page, opposite the page number. In this list of contents, the Section number is given following the title of the Section, and under each title appears a full synopsis of the subjects treated. This table of contents will enable the reader to find readily any topic covered.

DIES AND DIE MAKING, § 44, § 45

HARDENING AND TEMPERING, § 46

HEAT TREATMENT OF LOW-CARBON STEEL, § 47

HEAT TREATMENT OF LOW-CARBON STEEL
(Continued)

GAUGES AND GAUGE MAKING

GAUGES

CLASSIFICATION

1. A **gauge** may be defined as any standard of comparison, and gauges may, according to their purpose, be divided into two general classes—*reference gauges* and *working gauges*.

2. Reference gauges, or **master gauges,** are those which are preserved as standards of reference. They represent either an accurate subdivision of the ultimate standard of reference, or some arbitrary size or shape adopted for some purpose and required to be preserved. The ultimate standard of reference may be the standard bar for the meter or the standard bar for the imperial standard yard. Reference gauges are commonly kept for testing other gauges and are of many shapes and forms, which depend on the purpose for which they are intended.

Among the reference gauges of a more special class may be mentioned the *taper gauges*, which show the exact taper of the different Morse tapers; these reference gauges are, of course, in the possession of the Morse Twist Drill Company. In a broad sense, the ultimate standard of reference in the United States, which consists of the metric bar in the possession of the Government, is a reference gauge, as are also the bars known as bronze No. 11 and Low Iron No. 57, which were brought to the United States to represent the English standard yard.

3. Working gauges are those used in the shop for testing work. There are two general classes of working gauges: (1) gauges that represent an integral or fractional subdivision of the ultimate standard of reference, whether it be the imperial yard or the standard meter bar, and (2) gauges that are intended for preserving some special form. To the second class belong taper gauges and an infinite variety of special gauges for various irregular parts, such as are used in the manufacture of guns, sewing machines, and similar articles.

4. Gauges may also be subdivided into *definite gauges* and *limit gauges*. **Definite gauges** are those which establish a certain linear or angular dimension, but do not indicate any variations from the standard of the gauge. A **limit gauge** consists of two definite gauges that represent the limits within which the piece in question will pass inspection. A piece of work to pass inspection of the limit gauge must be of such size that it is smaller than the large gauge and larger than the small gauge of the pair.

ACCURACY OF GAUGES

5. Definite gauges in general, and also some limit gauges, cannot usually be made without suitable measuring instruments. The kind of measuring instrument to be employed naturally depends on the accuracy with which a size is to be established. In general, the limits of accuracy that may be obtained by the aid of the various measuring instruments are as follows:

1. Using a graduated standard scale, made by a reputable maker, that has its graduations cut in a dividing machine and setting calipers to it, the limit may be placed at .002 inch; that is, the size established may be .002 inch above or below the true size, giving a total variation of .004 inch.

2. Using a vernier caliper, if made by a reputable maker the total variation need not exceed .001 inch. It is well to remember that the total variation is twice the limit of accuracy, or the limit of variation.

3. By the aid of a vernier micrometer kept in first-class order and tested frequently by standard end-measure pieces

or reference disks, gauges can be made in which the total variation is within .0001 inch.

4. When the total variation is to be less than .0001 inch, a micrometer is not reliable enough, and recourse must be had to a standard bench-measuring machine in which a contact piece takes the place of the sense of touch of the toolmaker. With such a machine, work can be measured within a limit of accuracy of .00002 inch, or a total variation of .00004 inch. This measurement may be considered ordinarily as the commercial limit of accuracy; it is rarely required for gauges other than reference gauges.

The extremely accurate gauges are really accidents. Some gauges, in the final inspection, prove to be exceptionally accurate; others, within the commercial limits.

6. **Needless Accuracy.**—In gauge work, the toolmaker must guard against needless accuracy, since with every reduction in the limit of variation the cost of gauges is increased at an enormous rate. The permissible limit of variation is usually indicated by the purpose for which the gauge is intended, and a proper method of making it may be chosen by the exercise of judgment, which in turn will allow gauges to be produced that not only are "good enough" but also are reasonable in first cost. For instance, a gauge intended for testing the accuracy of a micrometer naturally needs to be accurate in itself, within the commercial limit of accuracy; while a gauge intended for trying the bore of a large steam-engine cylinder, say, 40 inches in diameter, will usually be accurate enough for the purpose if it varies not more than .01 inch from its true dimension. Likewise, a gauge intended for the blacksmith, who, on medium-sized work, would consider it very good indeed if he works to within a variation of $\frac{1}{16}$ inch, would be needlessly accurate if made closer than $\frac{1}{64}$ inch to its true size.

7. Sometimes it is rather difficult to decide on how closely a gauge must agree with its nominal size; in that case, the toolmaker must use his judgment. For instance, suppose that some part of a job is to be turned cylindrical and to fit a hole in some other piece, the two pieces of work being done by

different men working to gauges. Then, while it is of very great importance that the gauges used by the two men should agree, this does not necessarily imply that the actual size of the gauges must agree with their nominal size within the utmost degree of refinement. Judgment alone can determine the comparative accuracy required.

MATERIAL FOR GAUGES

8. The material most commonly used for gauges is *tool steel*, although for some work use is made of *machinery steel* that is case-hardened.

The treatment of tool steel for gauge work depends somewhat on the accuracy required and the hardness of the gauge. When a gauge made of tool steel, hardened all over, and probably clear through, or nearly so, is finished to an accurate size immediately after hardening, a gradual change of size or shape takes place, which, in the course of time, may cause a sensible deviation. This change of shape is ascribed to a rearrangement of the molecules, or minute particles, of the steel, whose former arrangement has been violently disturbed by the hardening process. Fortunately, this change of shape, which, according to observation, lasts for about a year, rarely exceeds .0005 inch per inch diameter; hence, it need be taken into account only for very accurate gauges. For reference gauges made within a limit of variation of .00002 inch, it must be taken into account if the nominal size or shape of the gauge is to be preserved. The usual way is to rough out the gauge immediately after hardening to within a small amount, say, .002 inch per inch diameter for a plug gauge, and then allow it to *season*, or *age*, as it is called, for about a year before finishing it to size. Usually a working gauge is worn out of true before these changes will become great enough to affect its accuracy.

9. Observation has led to the conclusion that this seasoning process can be greatly hastened by drawing the hardened gauge to a straw color after it has been roughed out. Heating the steel until it is hot enough to melt soft solder has the same

effect. A change takes place even after this, but the amount is so small as to be negligible for commercial work. As a matter of course, this method of seasoning steel leaves the gauges softer and hence they will wear faster. Whether this is a matter of sufficient moment to prohibit the use of this method, every person must decide for himself.

Another method of seasoning is to dip the gauge for a period of $\frac{1}{2}$ hour alternately in boiling water and water at freezing temperature. This process rearranges the molecules, without heating the steel enough to draw the temper.

10. Reference gauges that are used only for setting measuring instruments are often left soft; in which case they are made of well-annealed tool steel, which does not seem to change a sensible amount with age. Machinery steel, if well annealed in case any forging has been done in making the gauge, will keep its shape and size very well; being much softer than tool steel, it will naturally wear much faster. Gauges that are made from tool steel, but hardened only in parts, do not seem to be affected much, if any, by the aging, provided, of course, that the hardening extends over but a very small part of the gauge.

GAUGE MAKING

DIMENSIONAL GAUGES

CYLINDRICAL GAUGES

11. There is no recognized standard of proportions for cylindrical gauges. The plug handle should be so designed that a good tight hold may be obtained, because the gauge when properly fitted must be kept moving with a sliding and rotary motion to prevent it from sticking. In cylindrical gauges, the only essential sizes are the gauge sizes; all other dimensions are approximate and close enough if made within $\frac{1}{32}$ inch of the dimensions adopted. It is a waste of time and an evidence of misdirected skill to take much pains to work closer as far as these dimensions are concerned.

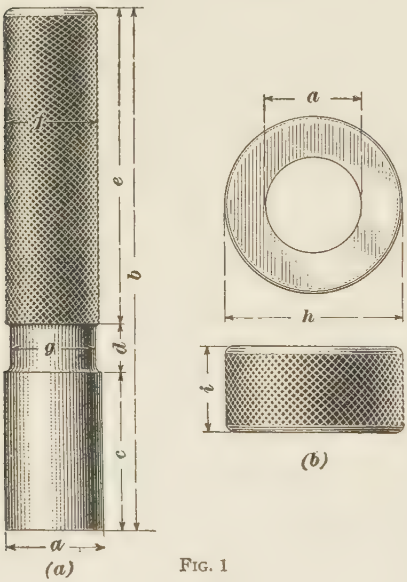


Fig. 1

Table I will aid the toolmaker in selecting dimensions. The letters in this table refer to Fig. 1 (*a*) and (*b*). For intermediate sizes, the dimensions given for the next largest size may be used.

12. Standard Plug Gauges.—In Fig. 2 is illustrated a form of plug gauge in extensive use. The undercut, shown by

the dotted lines in the end of the piece and having a length *a*, which is ground off after the gauge is lapped to size, is provided in order that the part of the plug that is lapped under size may

TABLE I

PROPORTIONS OF CYLINDRICAL GAUGES

Dimensions, In Inches

a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*
$\frac{1}{4}$	$3\frac{1}{8}$	1	$\frac{5}{16}$	$1\frac{13}{16}$	$\frac{7}{16}$	$\frac{7}{32}$	$1\frac{1}{16}$	$\frac{9}{16}$
$\frac{5}{16}$	$3\frac{1}{4}$	$1\frac{1}{8}$	$\frac{5}{16}$	$1\frac{13}{16}$	$\frac{1}{2}$	$\frac{9}{32}$	$1\frac{1}{16}$	$\frac{9}{16}$
$\frac{3}{8}$	$3\frac{1}{2}$	$1\frac{1}{8}$	$\frac{3}{8}$	2	$\frac{9}{16}$	$\frac{11}{32}$	$1\frac{1}{8}$	$\frac{9}{16}$
$\frac{1}{2}$	4	$1\frac{1}{8}$	$\frac{3}{8}$	$2\frac{1}{2}$	$\frac{9}{16}$	$\frac{7}{16}$	$1\frac{1}{4}$	$\frac{5}{8}$
$\frac{3}{4}$	$4\frac{13}{16}$	$1\frac{3}{8}$	$\frac{7}{16}$	3	$\frac{11}{16}$	$\frac{5}{8}$	$1\frac{5}{8}$	$\frac{3}{4}$
1	$5\frac{3}{8}$	$1\frac{5}{8}$	$\frac{1}{2}$	$3\frac{1}{4}$	$\frac{15}{16}$	$\frac{7}{8}$	$1\frac{13}{16}$	$\frac{7}{8}$
$1\frac{1}{2}$	$5\frac{7}{8}$	$1\frac{7}{8}$	$\frac{5}{8}$	$3\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{3}{16}$	$2\frac{5}{8}$	$1\frac{1}{4}$
2	$6\frac{3}{8}$	$2\frac{1}{8}$	$\frac{3}{4}$	$3\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{9}{16}$	$3\frac{1}{8}$	$1\frac{1}{2}$
$2\frac{1}{2}$	$6\frac{5}{8}$	$2\frac{1}{4}$	$\frac{3}{4}$	$3\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{11}{16}$	$3\frac{5}{8}$	$1\frac{5}{8}$
3	$6\frac{7}{8}$	$2\frac{1}{2}$	$\frac{3}{4}$	$3\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{11}{16}$	$4\frac{1}{2}$	$1\frac{3}{4}$

be removed. When lapping the end of the plug, the pressure of the lap is exerted only on a short length and the end of the lap becomes stripped of the abrasive. Owing to the short contact as the plug enters the lap, the lap is likely to be held at an angle, thus rounding off the corner of the plug; again, owing to the lap being stripped of the abrasive, when the lap is moved back on the plug the abrasive will cut the end of the plug smaller. The depth of the undercut *a* depends on the ability

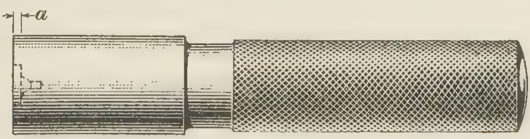


Fig. 2

of the toolmaker in using the lap. For plugs less than 2 inches in diameter, an undercut of $\frac{1}{8}$ inch is sufficient; for plugs greater than 2 inches in diameter, $\frac{3}{16}$ to $\frac{1}{4}$ inch is sufficient.

13. Small Plug Gauges.—In Fig. 3 is illustrated the form of plug gauge used for sizes too small to permit of centering. This type of gauge is made of drill rod pointed on the ends so that it will run in the hollow centers of the grinding machine. Fig. 3 (*a*) shows the plug itself and (*b*) a longitudinal section of the nurled handle in which the shank end of the plug is soldered. After finishing to size, the plug end is ground off roughly by hand to the line *a*, about $\frac{1}{8}$ inch from the base of the center *b*, and is finished square in the grinding machine, the work being held in the chuck. This distance must be allowed for when computing the length of the plug. The size of drill rod to be selected is that size next larger than the finished size of the plug, to provide an allowance for grinding. Such gauges are not turned. They are necked to a diameter *c* equal to the diameter of the plug, less .01 of the plug diameter. As shown in view (*b*), the diameter *a* of the hole that receives the shank of the plug is made to fit the shank *d*, view (*a*). The handles are made of machinery steel of suitable diameter. A piece of stock long enough for several handles is first turned up; the stock is then cut to lengths as wanted, and attached to the finished plug either by soldering or by being forced onto it.

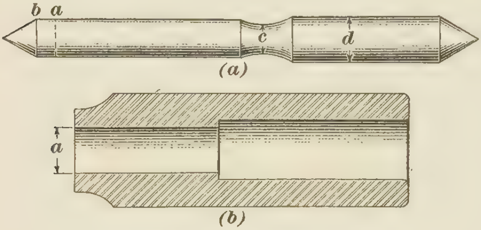


FIG. 3

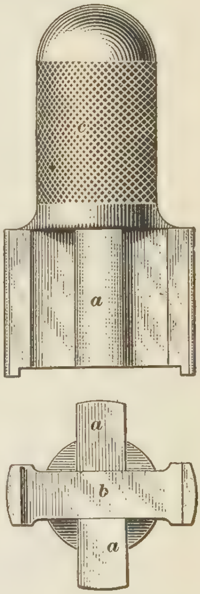


FIG. 4

14. Large Plug Gauges.—In Fig. 4 is shown a type of drop-forged plug gauge that is particularly suitable for the larger sizes. The forgings are usually bought all ready to be machined. The projections *a*, which are hard and are ground with the plug *b*, are soldered

to the plug after it is hardened. They serve to keep the plug from cramping while it is being lapped, and they are removed after the gauge is finished. The plug is hardened up to the handle *c* and the stresses are removed by seasoning before finishing to size.

In some cases, plug gauges greater than $\frac{1}{2}$ inch in diameter are made of machinery steel. The gauges are case-hardened to a depth of $\frac{1}{8}$ inch, cooled, hardened the same as tool steel, ground to within .002 inch of the finished size, allowed to season 3 months, reground, rough-lapped to within .0002 inch of finished size, allowed to season 6 months more, and then finished by lapping.

For large plugs, use is generally made of machinery-steel handles that screw into the body of the gauge. When possible, all handles should be smaller in diameter than the finished plug, in order that the gauge may be passed through a hole.

15. Grinding Allowance for Plug Gauges.—For grinding, an allowance of .012 inch should be provided for plug gauges that are less than $\frac{1}{8}$ inch in diameter, and for plug gauges greater than $\frac{1}{8}$ inch in diameter the allowance should be .015 or .02 inch. Small plug gauges are very liable to spring out of true in hardening. In general, it is easier to grind the small plugs straight after hardening than to straighten them by bending. The grinding of small plugs is a delicate operation, owing to their tendency to vibrate. They are generally ground on a special machine, using a steady rest, or on a bench lathe having a grinding attachment in the slide rest, the operator applying a slight pressure against the middle of the gauge by means of a piece of drill rod or some similar material. This pressure must not be enough to spring the plug; the weight of the rod, held between the fingers and allowed to bear against the gauge, is generally sufficient.

Plug gauges more than $\frac{1}{8}$ inch in diameter will not vibrate when grinding, provided the wheel face is narrow. Large plugs are ground on a suitable machine, using plenty of water, a free cutting wheel, the coarse feed for roughing, and the fine feed when finishing the last .0005 inch.

16. Lapping Allowance for Plug Gauges.—An allowance for lapping sufficient to remove the chatter and feed marks and to insure the work being cylindrical, should be made. When in doubt about the extent of these inaccuracies, the gauge is ground about .003 inch larger than the finished size and the wheel marks are first removed with a rough lap. After the wheel marks are removed, the plug is finished by the use of a finishing lap. If use is made of a proper wheel, feed, machine, and plenty of water, an allowance of .0003 inch will be sufficient for lapping plug gauges from $\frac{3}{16}$ inch to 3 inches in diameter.

17. Laps and Lap Holders for Plug Gauges.—Soft cast iron is a good material for laps; it holds its shape under hard usage and charges well. If an extremely fine finish is desired, the lap should be made of copper. The length of the lap is governed by the diameter and the length of the gauge. For gauges less than $\frac{1}{2}$ inch in diameter, the length of the lap may be made from $\frac{1}{4}$ to $\frac{1}{2}$ inch; for gauges from $\frac{1}{2}$ to 1 inch in diameter, it may be equal to the diameter of the gauge; for gauges more than 1 inch in diameter, it may be made $1\frac{1}{4}$ times the gauge diameter. The ends of the gauge, when lapping, must not be covered by the lap at all times; part of the gauge length must be exposed so that the lap may be moved lengthwise. The work is brought to the desired shape and the cylindrical grooves that may be formed are removed by moving the lap lengthwise. A very narrow lap must sometimes be used, especially when the gauge is composed of parts of different sizes. The roughing and finishing laps are usually reamed or bored as near the finished-gauge size as possible, one of the laps being expanded so that it may be used in the rough-lapping operation.

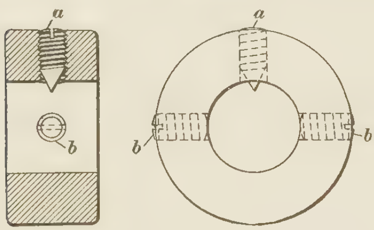


Fig. 5

18. In Fig. 5 is illustrated a very satisfactory holder for laps for plug gauges up to $\frac{1}{4}$ inch in diameter. This lap holder

has one expanding screw *a* and two closing screws *b*. These screws give good control of the lap bushing, the outside diameter of which is made a few thousandths of an inch smaller than the bore of the holder. The outside of the holder is nurled.

In Fig. 6 is shown a common and useful holder for laps for larger plug gauges. This lap holder is opened by loosening the screw *a* and tightening the screw *b*, and closed by loosening the screw *b* and tightening the screw *a*. For large laps, a handle is inserted in the holder to relieve the strain on the hands. The lap holder is usually made somewhat shorter than the lap.

19. Lapping Plug Gauges.—F F F emery or 15-minute carborundum mixed with sperm oil and a little kerosene makes a good cool lapping compound; that is, a compound that will cut without heating. The result of heating is a gumming up, or caking, of the oil, which condition prevents the removal of the metal. The ideal lubricant is one that will remain liquid when lapping. The F F F emery or 15-minute carborundum is used when finishing the gauge. A finer grade of abrasive would float in the oil.

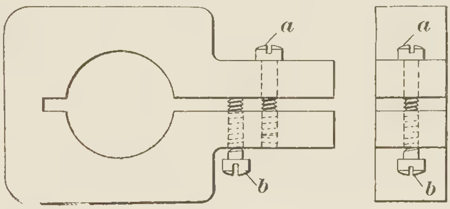


Fig. 6

In the lapping operation, the speed of the plug gauge should be no faster than is required to make the work comfortably warm. If it becomes too warm, the heat will dry up the oil and thus cause the lap to be glazed in spots. A glazed lap will leave streaks on the surface of the work. The abrasive dish is placed under the work and at an angle with it in order that the oil may run to one side, leaving the abrasive exposed.

The abrasive is applied to the work, which is kept flooded, with a brush, and the lap is held snug to the work, being quickly moved back and forth. When near the finished size, the machine is slowly revolved by hand, while the lap is pushed lengthwise; this operation will show the circular grooves in the gauge and must be continued until they disappear. A new lap

and the oil in the abrasive dish after the coarser particles have settled are used for finishing. In taking up the oil, care must be taken not to cause the coarser particles of the abrasive to float.

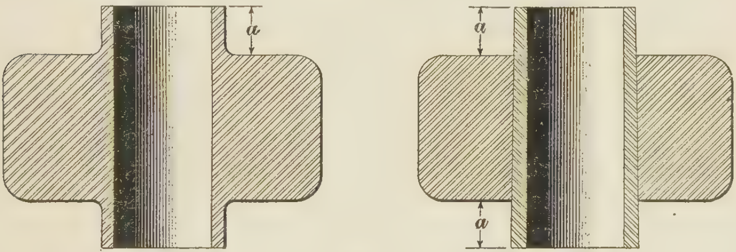
20. The plug gauge shown in Fig. 4 is liable to become undersized on the edges, as they take the heavy charge of the lap. To prevent this effect, the lap is used rather dry, or the gauge is draw-lapped to size. When draw-lapping, the machine is stopped and the lap is moved back and forth over the plug lengthwise while the work is revolved slowly by hand. When finished, a light blow will remove the pieces *a*.

21. The process of lapping heats the gauge considerably; if it is measured while hot, it will be below size when it has cooled to the normal temperature, owing to the contraction of the steel in cooling. For this reason, the gauge must be cooled to the temperature of the room before it is measured, if accuracy is required. To reach this temperature, the gauge should be inserted into a bucket of water that has been in the room for an hour or more, and left in the bucket long enough to be cooled down to the temperature of the water. The lapping must be repeated until the gauge is of the correct size, within the limit of accuracy determined necessary. In sliding the lap back and forth, the lap is sure to cut faster at the extreme end of the gauge, which is therefore lapped slightly tapering, as careful measuring will show. In order that the gauge may be straight throughout, the end, which is undercut as shown in Fig. 2, is ground off after the gauge is lapped to size. To finish the end, it is ground off square in a grinding machine while the gauge is held in a chuck.

22. Forms of Ring Gauges.—Ring gauges may be made of tool steel and hardened all over, when they are known as *solid-ring gauges*, or they may have a body of machinery steel into which a hardened tool-steel bushing has been forced, when they are called *inserted-bushing ring gauges*. Each of these forms has its own advantages and disadvantages. As far as the tool-steel, or solid-ring, gauge is concerned, it is cheaper in first cost and not liable to be indented by accidental blows;

on the other hand, it is likely to be cracked in the hardening process, will be changed in shape and size while being seasoned, and is worthless when worn. The second method of construction is slightly more expensive; but this disadvantage is offset by the comparative absence of change in seasoning and the possibility of making a new bushing at less cost than the tool-steel ring gauge when the gauge becomes worn.

23. Making a Solid-Ring Gauge.—To make a solid-ring gauge, a piece of annealed tool steel is used; it must be long enough to give the form shown in Fig. 7 (*a*). The dimension *a* depends on the skill of the toolmaker, as is the case with the undercut *a*, Fig. 2; in general, these dimensions should be



(*a*) FIG. 7 (*b*)

equal. The diameter of these projections is usually made from $\frac{1}{8}$ to $\frac{3}{16}$ inch larger than the gauge diameter. The outside is finished, the size stamped on the ring, and the gauge hardened. For the larger sizes, the inside is now ground to within a small fraction of the finished diameter, if an internal grinding device is available; for sizes too small to admit of grinding, the inside is lapped nearly to size. The gauge is now seasoned and brought to the finished size by lapping, using the plug, which has been made previously, as a gauge when testing the ring. Great care must be taken to have the plug and the gauge at the same temperature while trying the fit, and the plug and the ring absolutely free from the abrading material used for lapping. When trying the gauges, mutton tallow or vaseline is used as a lubricant. The operation of lapping will leave the ends of the gauge slightly bell-mouthed; when the plug just commences to enter at either end, it will show the toolmaker

that the ring gauge is lapped very nearly to the finished size. For the final lapping, the very finest of flour abrasive must be used with a copious supply of oil.

24. The fit of the plug in the ring should be so nearly perfect that when the temperature of the plug is raised to blood heat by holding it in the hand for a few minutes, it will not enter the ring gauge, which is here supposed to be at a temperature of about 70°. In testing the fit, an attempt should be made to enter the plug by a combined sliding and rotary motion. If the plug sticks, it should not be driven out under any circumstances, but the ring gauge should be heated a little; heating will quickly expand it enough to allow the plug to be withdrawn by hand. If the plug is driven out when stuck, both the plug and the ring gauge may be badly scored. When the ring gauge has been lapped to a perfect fit, the projections at each end are ground off flush with the faces.

25. Making an Inserted-Bushing Ring Gauge. When making a ring gauge with an inserted bushing, Fig. 7 (*b*), the machinery-steel collar may be made first, finishing it all over. The central hole is bored and reamed straight, making the length of the gauge equal to $1\frac{1}{2}$ times its diameter. The tool-steel bushing is bored and turned, leaving a grinding allowance on the inside and outside. The bushing is made so long that when driven home the ends will project on each side of the gauge. The bushing is hardened and the inside is ground and lapped true and round to the finished size. The bushing is now placed on a true-running arbor, and the outside is ground to fit the hole in the collar. The bushing is now removed from the arbor and driven home lightly. The gauge is finished to size by being relapped to fit the plug. The projecting ends of the bushing are ground off, and if a fine external finish is desired it is finished by polishing.

26. Grinding and Lapping Allowance for Ring Gauges.—An allowance for grinding of .005 inch is usually made for ring gauges between $\frac{1}{2}$ and 1 inch in diameter, and of .01 inch for ring gauges greater than 1 inch in diameter. On account of the diameter of the wheel or of the diamond lap used

as a wheel, ring gauges less than $\frac{1}{4}$ inch in diameter are generally lapped without grinding. An allowance for lapping of .001 inch may be made for holes up to $\frac{1}{16}$ inch in diameter, if

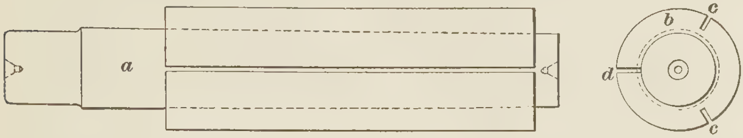


FIG. 8

reamed smooth when soft; .0015 inch for holes from $\frac{1}{16}$ to $\frac{1}{4}$ inch in diameter; and .0025 inch for holes from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter. Holes that have been properly ground, require an allowance of about .0005 inch for lapping.

27. Laps and Lap Holders for Ring Gauges.—In Fig. 8 is shown an arbor *a* designed to hold shell laps *b* that have been taper-reamed. Cast iron is a very satisfactory material for shell laps; they are usually turned to the diameter of the gauge on the arbor on which they are to be used and are split after turning. It is advisable to cut two or more shallow slots, as *c*, into the shell. These slots with the slot *d* that splits the shell, serve to hold the abrasive and oil. The depth of the slots *c* should be greater for thicker shells. They aid in expanding the lap, which is done by driving the lap farther on the tapered arbor. It is best to use a new lap for finishing ring gauges. A lap that has been used for roughing will be somewhat out of round, owing to wear and expansion. In case a number of like gauges are to be made, all the holes are first rough-lapped and then finish-lapped.

The length of the roughing lap is usually about twice the thickness of the ring gauge, and it may even be three times this

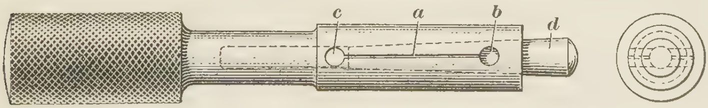


FIG. 9

thickness; the length of the finishing lap is about three-fourths the thickness of the gauge. Should the lap be too small to be taper-reamed, a lap of the type shown in Fig. 9 may be used.

This lap is split by the two slots *a* joining the drilled holes *b* and *c*, and is expanded by driving in the taper pin *d*. The

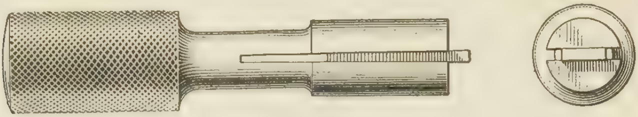


FIG. 10

hole *b* is placed close enough to the end of the lap to allow the metal to stretch when the lap is expanded. Brass is a good material to use for a lap of this type.

28. Fig. 10 illustrates a type of lap used for roughing and removing local spots; it is liable to follow the curve of the hole lengthwise if the hole is curved. Laps should be as solid as possible. A flexible lap will follow a hole smaller than $\frac{1}{10}$ inch in diameter and long in comparison to its length, as shown in Fig. 11. Should a hole of this size be lapped without grinding, there is danger, when finished, of its being curved, as shown somewhat exaggerated in the illustration. When testing the size of these small holes with a plug gauge, the gauge, being flexible, will spring, causing the toolmaker to think the hole is small in the center. When finishing a hole, care must be taken lest the bell mouth extends in the part of the hole to be preserved for the gauge. The narrow finishing lap is used in the center of the hole and is not allowed to run out at the gauge ends. This lap is used as dry as it is possible to use it without glazing.

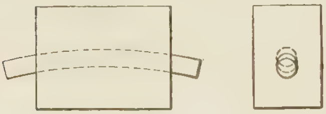


FIG. 11

Small ring gauges may be tested by running into the gauge, to the position shown in Fig. 11, a wire that fits the gauge. The ends of the wire are next laid on the flat surfaces *a* of the cast-iron block, Fig. 12, which is chambered at *b* to allow the wire to rest on the surfaces *a*. If the wire lies flat on the surface

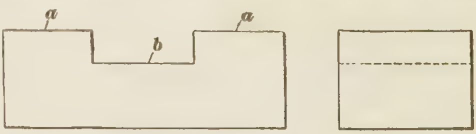


FIG. 12

before inserting it in the gauge, it will lie flat after its insertion, unless the hole is curved.

29. Fig. 13 shows an arbor used to hold long laps, the screws *a* expanding the arbor instead of the taper plug, as shown in Fig. 9. Very small laps are used on this type of arbor; they are not slotted, but are reamed as large as possible, leaving a thin shell of metal, which is forced over the arbor.

30. Lapping Ring Gauges.—Drill rods and diamond dust of different grades are used for lapping extremely small

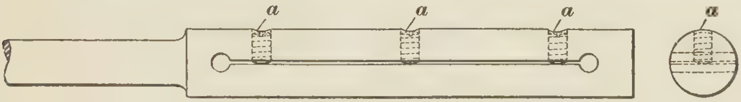


Fig. 13

holes straight. F F F emery and 15-minute carborundum are employed for lapping the larger ring gauges. The lap may be enlarged and charged with the abrasive at the same time by rolling it between two files covered with the abrasive. The files act as nurls, lifting up parts of the metal surface of the lap, which, when the lap is inserted into the hole, are closed upon the abrasive. In this way, a greater proportion of the abrasive is retained on the surface of the lap.

THREAD GAUGES

31. Forms and Proportions of Thread Plug Gauges. In Fig. 14 are shown the standard forms of thread plug gauges. The type of gauge generally used for reference purposes is illustrated in (*a*) and (*b*) and the form of working gauge in (*c*). The diameter *a* of the cylindrical ends of the gauges shown in (*a*) and (*b*) is made equal to the diameter of the root of the thread. As a working gauge is almost always used to gauge work that has been drilled, or bored, a little larger than the diameter of the root of the thread, it is not made with a cylindrical end. The diameter *b* is made a little less than the diameter of either the root of the thread or the handle; the diameter *c* is made a little less than the diameter of the root of the thread and the

proportions of the handles are about the same as those given for cylindrical plug gauges. Any shape of thread may be cut on the gauge, but those generally used are the **V** and United States standard threads. When reference gauges having the United States standard shape of thread are made, the threads are shaped sharp at the root; but working gauges of the United States standard form of thread are constructed with the nominal root diameter.

32. Soft and Hardened Thread Gauges.—Thread gauges are made of tool steel and may be left either soft or

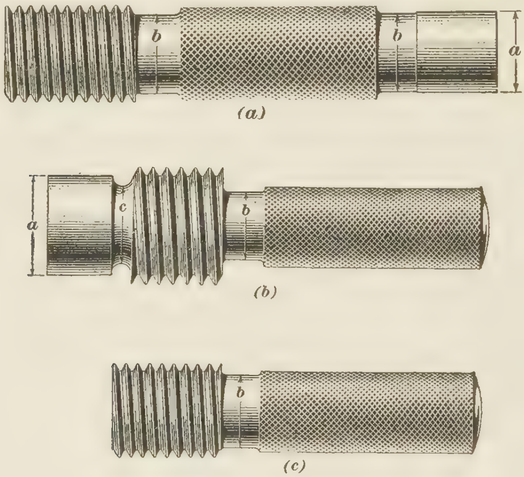


Fig. 14

hardened. As reference thread gauges are subjected to little wear, and as the distortion caused by hardening is likely to render the finished gauge less accurate than one not hardened, such gauges are usually finished soft. Working thread gauges are subjected to considerable wear; consequently, in order that their correct form may be retained longer, they are frequently hardened. As the finishing of a hardened thread gauge is very expensive, some concerns prefer to use the working gauges in the soft condition. In this case, they are frequently tested by the gauge-making department, new gauges being made when required.

Since reference thread gauges are not hardened and working gauges are liable to be worn out of true before the seasoning changes become great enough to affect their accuracy, thread gauges are not aged.

33. Chasing Thread Plug Gauges.—The cylindrical part of the gauge to be threaded is turned to within .0001 inch of its nominal dimension and the tool for chasing the thread is prepared with great care. To chase an accurate thread, a lathe having a perfect lead screw must be used. The cutting edge of the threading tool must be ground as near the thread shape as possible, and the top of the tool must be ground flat so that, when set up in the lathe, its plane will contain the center line of the lathe spindle and be parallel to the ways of the lathe. The tool is reground for the finishing cuts. The thread may be measured by means of a thread micrometer or wires and an ordinary micrometer, as explained in *Toolmaking*, Part 2.

34. If a soft working gauge is to be made, the work is fitted to a reference ring gauge of the same dimension and pitch. If a hardened working gauge is to be made, the thread may be cut .0005 inch larger than that dimension to which the gauge would have to be made, so that the size of the gauge after hardening would be nominal. The amount that the steel will contract or expand during the hardening process is found by experiment. If a 1-inch plug gauge will shrink .002 inch when hardened, the thread should be made, when soft, .0015 inch larger. A minimum amount of stock should be left to be lapped; if possible, only just enough to brighten the threads.

When plugs are hardened, the lead is usually changed somewhat. The hardening may cause the lead to become greater, spoken of as a + change, or it may cause it to become smaller, spoken of as a − change. The + or − change in the lead depends on the steel used and the treatment it receives. The amount that the steel changes when hardened is determined by experiment.

35. When making thread plug gauges to be hardened, the amount that the lead will change is first determined and a

thread having a lead that, after hardening, will be nominal is chased on the plug. Suppose it has been found that a 1-inch plug having sixteen threads to the inch will lengthen, when hardened, .0016 inch per inch of length, then, the lead of the plug will be increased .0001 inch. To compensate for this change, a thread having a lead of $\frac{1}{16}-.0001=.0625-.0001=.0624$ inch is chased on the plug.

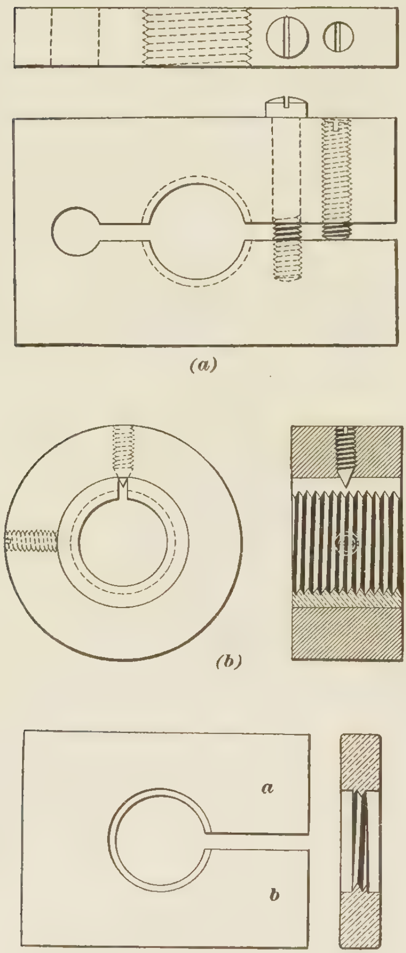


FIG. 15

If a working gauge to be hardened is chased so that it will fit the reference ring gauge snugly, it will probably be near enough to size after hardening and lapping.

Reference gauges are finished with the thread tool. They are neither hardened nor lapped. The final test for size of a reference thread plug gauge is the measurement made by the wire and micrometer method.

36. Lapping Thread Plug Gauges.—In Fig. 15 are shown forms of laps used for lapping the threads of plug gauges. The threads of the laps are finished by tapping, using a master tap or one that has been found to have nearly a perfectly shaped thread. The laps (*a*) and (*b*) are adjustable, and all the laps shown are made of cast

iron or of brass. The cast-iron laps, however, are not used for lapping sharp threads, as the edge would be apt to crumble away. The lap shown in (*c*) is a single-thread lap and is used for reducing the sides and root diameters of the threads locally. This lap is not provided with adjusting screws, closure being accomplished by the pressure of the hand against the ends *a* and *b*.

37. One of the sides of the lap shown in (*a*) is made plane and at right angles to the thread axis in order that the truth of the lead of its thread may be tested after it has been slotted and adjusted. Should the lap be distorted, one of the sides having

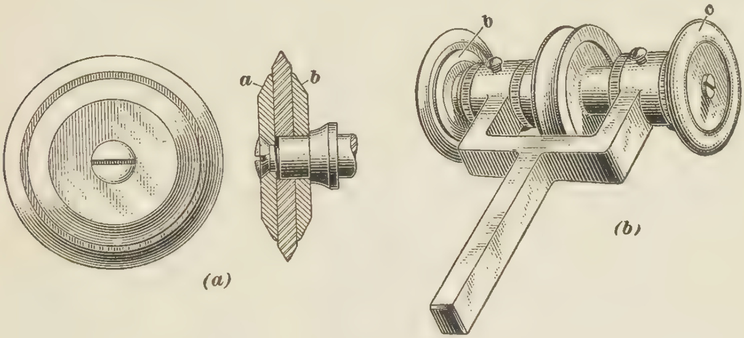


FIG. 16

been made flat as described, it may be held in position by clamping the plane side of the slotted end to a flat piece of steel.

When lapping, a fine abrasive, 15-minute carborundum, or its equivalent, is used with a good, but not tight, pressure.

38. If the hardening distortion changes the lead of the gauge thread more than .0015 inch per inch of length, a soft-steel 60° disk, Fig. 16 (*a*), about $2\frac{1}{2}$ inches in diameter, is used to correct the error. This disk is mounted on a tool-post grinding attachment (*b*), between the washers *a* and *b*, in (*a*). This attachment is held in the lathe tool post, and the grinding head is supplied with power from an overhead drum and a $\frac{1}{8}$-inch round rawhide belt. The hand wheel *c*, in (*b*), serves to hold in position the arbor carrying the washers and disk, and also as a balance wheel. The disk is charged with diamond dust, using a roll, and the machine is geared to cut a thread of the

desired pitch. The operation of correcting the lead of the thread in this way is the same as cutting the thread with the lap replacing the threading tool. Care should be taken not to force the lap, as too much pressure will strip the diamond dust from the disk. When the lap is cutting properly, sparks similar to those from a grinding wheel will fly.

If the plug is to be a working gauge, it is lapped until it fits the reference ring gauge as perfectly as required and its lead, as shown by the following test, is correct.

39. Testing Lead of Thread.—The truth of the lead may be tested by the use of the device shown in Fig. 17, which consists of a $1'' \times 3'' \times 6''$ bedplate *a*, a block *b* on which the handle of the plug is rested, a nut *c* containing one thread of the size and pitch of the thread to be tested, and a block *d* supporting the micrometer head *e*. The nut and blocks are secured to the bedplate with screws, as shown, the block *b* may be made adjustable as to height, and the nut *c* may be made adjustable as to position by supplying additional screw holes in the bedplate. A ball *f* is secured to the end of the plug *g* by means of shellac. Additional nuts may be supplied for threads of different sizes and pitches.

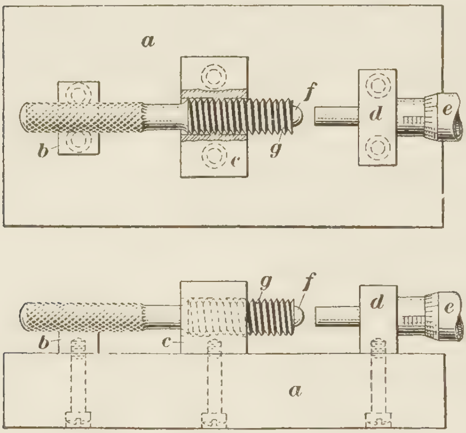


FIG. 17

To test the lead of the thread, the plug is started in the nut, the end of the spindle of the micrometer is brought in contact with the ball *f*, and the reading is recorded. The plug is advanced one turn at a time, the readings being taken and recorded at each turn, until the end of the plug thread is reached. To assist in turning the screw an exact revolution, a setting

mark is made on the nut *c* and another mark on the handle of the plug. The plug is then turned until these marks are alined. The difference between the successive readings should be equal to the lead of the thread.

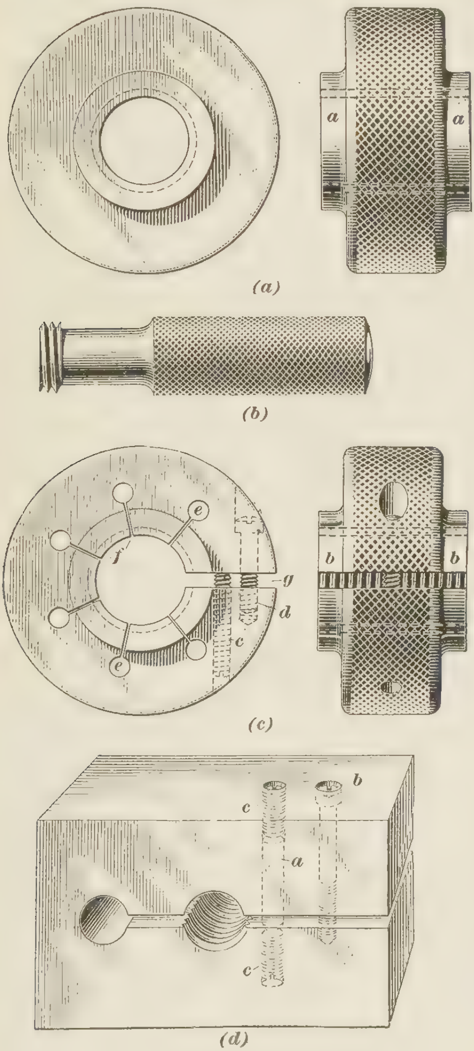


Fig. 18

40. Making Master Taps.—Master taps are generally made as described in connection with the making of taps in *Toolmaking*, Part 2. Great care is used, however, to compensate for the change in lead when hardening as is explained in connection with the chasing of thread plugs. Master taps are not lapped, although they may be ground, using the soft-disk and diamond-dust method. When this is done, the tap is run backwards in the lathe. When the threads are finished in this way, they are provided with a slight clearance and the cutting points are rounded a little as the disk leaves them. The flutes are ground back enough to remove the low part of the cutting edge.

41. Solid-Ring Thread Gauge.—In Fig. 18 (*a*) is shown a form of solid-ring thread gauge. This gauge is generally used for working purposes and may be made either soft or hardened. As in the case of plain ring gauges, the lapping of the gauge tends to make the gauge bell-mouthed at the ends. Consequently, gauges to be hardened are made with projections *a*, which are afterwards ground off. As the soft gauges are not lapped, these projections are not needed when making them.

Ring thread gauges are made by fitting them to reference plug thread gauges. Plug thread gauges, having but two threads, as shown in Fig. 18 (*b*), are used to locate errors in lead and shape of thread when chasing, and lapping the thread. Generally two of these plugs are employed, one of the nominal dimension of the gauge and one .0005 inch smaller than the nominal size. The roughing cuts are removed with the lathe threading tool and the finishing cut with a master tap. If the gauge is to be hardened, enough stock should be left to be removed by lapping that the thread will be brightened.

42. The hardened ring gauge is next hardened, and the thread is finished by lapping The ends *a* are then ground off, using plenty of cooling liquid to prevent the gauge from being distorted by the heat generated. It is best to rough off these ends by holding the work in the hand. When thus held, not so much heat is generated as would be if the work were held in a machine, because the work is not in continuous contact with the wheel; also, the hand will detect the presence of heat before the work becomes warm enough to distort the gauge. To finish the ends, a threaded piece of steel is gripped in the chuck of the grinding machine, the gauge is screwed on this piece, and the ends are in turn ground plane.

43. Adjustable, Ring, Thread, Working Gauge.—An adjustable, ring, thread, working gauge is shown in Fig. 18, (*c*). As in the case of the solid gauge just described, the projections *b* are used only when the gauge is to be hardened. After the thread is chased and tapped, the holes to receive the screws *c* and *d* are drilled and tapped; after this, the holes

e and the slots *f*, to provide the spring needed to permit adjustment, are drilled and cut, the slots *f* being cut with a hack saw. To open the thread, the screw *d* is loosened and then the screw *c* is tightened; and to close the thread, the screw *c* is loosened and then the screw *d* is tightened.

The slot *g* is next cut, and the burrs produced on the threads by cutting the slots are cleaned out. If the gauge is to be left soft, the screws *c* and *d* are fitted to it and the gauge is ready for use. If the gauge is to be hardened, it is hardened at this time; then the screws *c* and *d* are fitted to it, and the thread is finished by lapping. After lapping the thread, the projections *b* are ground off in the manner explained in connection with the solid-ring gauge.

44. Ring, Thread, Reference, Gauge.—In Fig. 18 (*d*) is shown an adjustable, ring, thread, reference gauge. A close-fitting pin *a* is provided to maintain the alinement of the lead of the thread. The thread is opened by loosening the screw *b* and then tightening the screws *c*; it is closed by loosening the screws *c* and tightening *b*. This gauge is made from a piece of flat tool steel. It is first machined all over, making the opposite sides plane and parallel; after this it is chucked centrally in the lathe, and the threaded part is chased nearly to size and finished with a master tap.

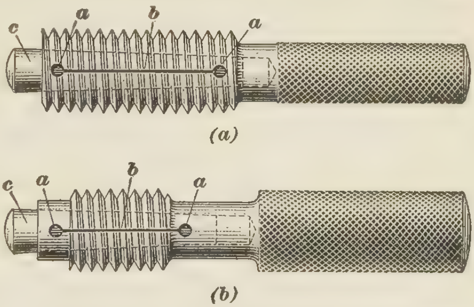


Fig. 19

After cutting the thread, the holes are drilled and tapped, the work is slotted, and the burrs produced on the threads by cutting the slots are cleaned out. After fitting the pin and screws to the gauge, it is ready for use.

45. Lapping Thread Ring Gauges.—In Fig. 19 (*a*) is shown a form of lap used for lapping ring thread gauges and in (*b*) is shown the lap used to correct the irregularities of the

threads in the center of the gauge. These laps are usually made of cast iron, brass, or machinery steel, although cast iron is not used for sharp V threads, as it is very liable to crumble away at the sharp edge. The same care is exercised in chasing the thread of these laps as in chasing plug thread gauges and master taps. Holes *a*, joined by a slot *b*, and a tapered hole to receive the pin *c* are cut in the laps. As the laps wear, they may be expanded a little by tapping in the pin *c*. The length of the threaded part of the lap shown in (*a*) is usually made equal to twice the thickness of the ring gauge, and the length of the threaded part of the lap shown in (*b*) is made equal to one thickness of the ring gauge. When lapping, a fine abrasive, either 15-minute carborundum, its equivalent, or diamond dust, is used. Diamond dust is generally employed on the smaller ring gauges and carborundum on the larger sizes.

When the gauge is hardened, it is very liable to expand into the bore, making the ends of the gauge bell-mouthed. The lap shown in (*b*) is used to correct this distortion.

As laps wear out of shape quickly, and are rather easily made, plenty of them should be on hand when ring thread gauges are to be lapped.

END-MEASURING GAUGES

46. An **end-measuring gauge**, shown in Fig. 20, may be made of a cylindrical bar having its ends squared and finished to the correct size. A piece of tool steel about $\frac{1}{32}$ inch longer than the inside gauge is to finish is hardened at the ends, or all over, if of short length. The pieces *a* are then soldered on the ends, drilled, and centered. The outside is next ground straight and true and the pieces *a* are broken off. The ends are next ground square and flat in a grinding machine, holding the gauge in a chuck and finishing to within a small amount of the finished size. The gauge is finished by lapping.

FIG. 20

47. Lapping End-Measuring Gauges.—In order to insure parallelism of the two measuring surfaces, the device

shown in Fig. 21 may be used for lapping gauges of this type. As shown, it has a central hole bored to a good sliding fit for the gauge. A narrow ring of liberal outside diameter is faced off square with the hole; the facing may be done at the same chucking in which the hole is bored, or by mounting the device on a true-running arbor after boring the hole and then facing it while running the arbor between the centers. The gauge is inserted into the hole and pushed down level with the faced end; by moving the device to and fro on a small, planed, cast-iron plate charged with fine abrasive and oil, the ends of the gauge may be lapped true and square and parallel to each other.

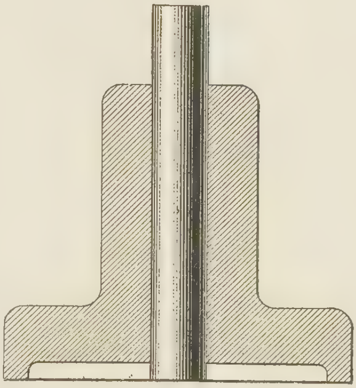


Fig. 21

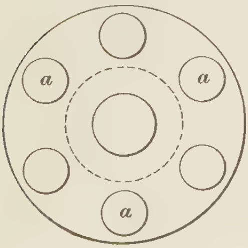


Fig. 22

Fig. 22 shows the same fixture as that illustrated in Fig. 21, except that the ring around the bottom is replaced by the hardened pins *a*. These pins are faced off true, using a true-running mandrel, on a grinding machine. If there are many gauges to lap, it is better to use this design of fixture.

48. Making Large End-Measuring Gauges.—In Fig. 23 is illustrated a type of large end-measuring gauge. The ends of the center piece *a* are faced off parallel on the lathe centers; and the end pieces *b* are hardened, ground, and lapped parallel and to size; the centers are left in the center piece when finished.

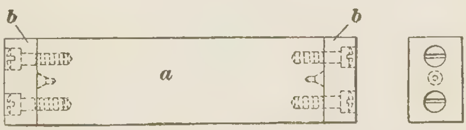


Fig. 23

CALIPER, OR SNAP, GAUGES

49. Advantages.—A caliper, or snap, gauge is superior for some work to a cylindrical gauge. In the first place, a caliper gauge is adapted to measuring work having a cross-section other than round; for cylindrical work done between centers, it is not necessary to take the work out of the lathe to test it. Furthermore, by applying it on different parts of the work, the roundness and parallelism can be tested; such a test cannot be made with a cylindrical gauge. An alleged cyindrical piece of work may apparently be a very good fit in a ring gauge and be slightly oval at the same time, or have high places that balance each other, or be under size away from the end of the work. Unless the divergence from a circle or parallelism is considerable, the ring gauge will not show it; the caliper gauge will, however, show a very minute deviation. The caliper gauge may also be used for measuring a neck between two collars.

FIG. 24

50. Form of Caliper Gauges.—Caliper gauges may be designed in a great variety of forms, to suit different purposes and conditions. The most common forms of external gauges are those shown in Figs. 24, 25, and 26. In order to pass over cylindrical work, the depth of the opening must be slightly more than half the gauge size. When a caliper gauge of this kind is intended for flat work, the depth of the opening is to be made to suit the work.

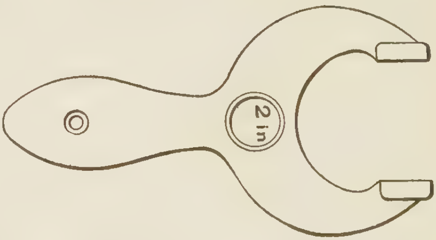


FIG. 25

When caliper gauges take the place of plug and ring gauges, they are usually made combined. In Fig. 27 is shown a standard

drop-forged, combined external and internal caliper gauge, and in Fig. 28, the type of caliper gauge used for very small outside dimensions. The center piece *a*, Fig. 28, determines the size of the gauge. There is no wear on this piece; therefore, when it is once made to the correct size, its thickness remains constant. When the gauge becomes worn, the sides *b* are relapped flat.

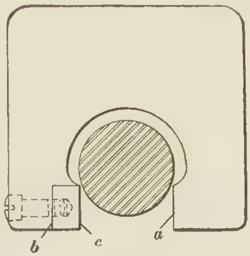


FIG. 26

51. Making Caliper Gauges.—Except when the size of the outside gauge is so large that an inside micrometer can be applied, the inside gauge must be made first; the outside snap gauge is then finished to fit the inside gauge. If the inside gauge simply serves the purpose of a reference gauge to preserve the gauge size, it may be an end-measuring gauge.

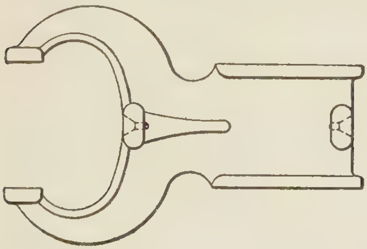


FIG. 27

Caliper gauges not previously ground, and having not more than .003 inch to be removed can be lapped in a comparatively short time. Should the amount of stock to be removed be greater than .003 inch, it will be found necessary to grind the gauge to a dimension within .003 inch of the finished size.

52. As the gauge ends are the only surfaces hardened, an **allowance for grinding** of .007 inch on each surface is enough. The **allowance for lapping** depends on the condition in which the wheel leaves the surface. If ground on a good surface grinder, .0005 inch is sufficient.

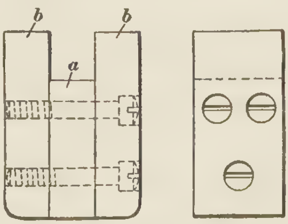


FIG. 28

53. Grinding Caliper Gauges. One way of grinding caliper gauges is illustrated in Fig. 29. The gauge *a* and the guard pieces *b* are attached to the

centered parallel strip *c* by the clamps *d*; and the parallel, together with the gauge, is held in a fixed position on the centers of the grinding machine in any convenient way. The wheel *e* is moved in and out by means of the cross-feed of the machine.

The gauge may also be held, as shown in Fig. 30, in a vise, or on an angle iron on the bed of a surface-grinding machine. The guard pieces *a* are clamped or soldered to both sides of the gauge and ground with it. They overcome the tendency of the gauge to crown; that is, to become high in the center. These pieces are also used on gauges smaller than $\frac{1}{4}$ inch thick to steady the lap, which is liable to wabble and thus crown the

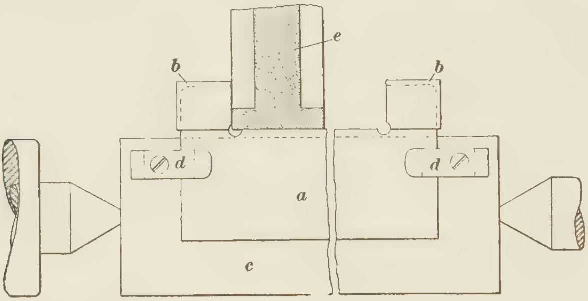


FIG. 29

surface. Very accurate work can be ground in this way; in fact, some manufacturers do away with lapping such gauges, merely frosting them with an oilstone.

54. The bearings should be adjusted as often as is necessary, in order that the wheel may have no end motion. A soft stiff **T**-shaped wheel, Fig. 30, is used. If the wheel is cutting properly, there will be a good spark and no metallic sound; the wheel will crown the surface if it makes a ringing sound when cutting. The part of the face of the wheel that does the cutting is employed, the face of the wheel not being run past either edge of the gauge. A knife-edge straightedge is used to test the accuracy of the plane surface produced. When making a gauge of the type shown in Fig. 26, the sides *a* and *b* are first ground parallel. The block *c* is then made so that the sides are

parallel and of a thickness that will give the proper size for the finished gauge. The internal part of the gauge shown in Fig. 27 is ground while it revolves on the centers of the grinding machine.

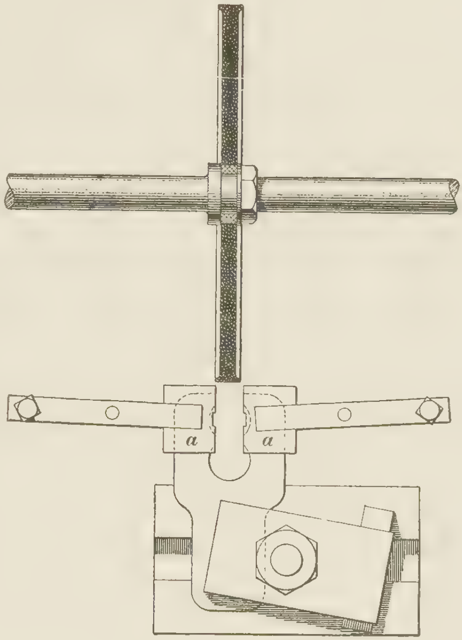


FIG. 30

55. Lapping Caliper Gauges. An adjustable parallel lap made of close-grained cast iron is shown in Fig. 31. These laps are held together with clamps, and are enlarged by tapping one end of the lap with a lead hammer. A taper of $\frac{1}{4}$ inch to the foot is generally used for the sliding parts. They are employed for gauge sizes up to 3 inches. The sides are parallel and the lap is set to a thickness that will give the proper size for the finished gauge.

When lapping a caliper gauge with this lap, the gauge is held in the position shown in Fig. 30, and an up-and-down motion is imparted to the lap when pushing and pulling it through the gauge. If the gauge surface becomes a little crowned, a slight


FIG. 31

depression is worked in the high spot with an oilstone pencil. The lap is kept flat and snug to the work and well charged with the abrasive. A flat, cast-iron surface charged with abrasive

is used to keep the gauge lap flat and to charge the lap with the abrasive. The lap is also flooded with the abrasive when in the gauge.

The lap shown in Fig. 31 makes a good adjustable templet; measurements taken from this lap will usually be near enough to size. When surfaces are lapped without grinding, this type of lap is used. The best surface of the gauge is lapped first; the side of the lap which works against the finished surface is cleaned of the abrasive; the other surface is then lapped to size. The internal end of the gauge shown in Fig. 27 is lapped to size in the manner explained in connection with the lapping of the cylindrical gauge shown in Fig. 4.

LIMIT GAUGES

56. Limit of Variation for Limit Gauges.—By trying them into a hole or over a shaft, cylindrical and caliper gauges show whether or not the hole or the shaft is of the correct size. They do not show, however, the amount of variation from the true size, or whether the variation in the size of the hole or the shaft is sufficient to prevent one from fitting the other with the requisite degree of accuracy, or whether they will go together at all. There is very little work indeed that must be as close a fit as a plug gauge into its ring gauge; in nearly all work, quite an appreciable deviation from this fit is permissible. Naturally, the amount of deviation varies with the circumstances of each particular case. Furthermore, to finish a shaft, and bore a hole to receive it to an accurate size, is a very expensive job and rarely necessary. Then, in order to prevent needless accuracy in finishing two pieces of cylindrical work that are to fit each other, limit gauges are employed.

57. Thus, if a shaft is to be 1 inch in diameter, and it has been decided from previous experience and observation that the fit will be close enough if there is .002 inch difference between the size of the shaft and the size of the hole, two sets of cylindrical and caliper gauges differing from each other by the allowable variation mav be used as limit gauges. One of the

sets would usually be made one-half the allowable variation larger than the nominal size and the second set would be made just as much smaller. In using the plugs, the smaller plug must enter the hole and the larger plug must not enter. Likewise, the larger ring gauge must go over the shaft and the smaller one must not go over. If this is the case with both shaft and hole, the total variation in the fit is not more than .002 inch for the case considered and may be considerably less.

58. Now, suppose that it has been decided that the shaft must fit the hole with a given minimum amount of clearance and that the hole is to have the nominal dimension. In this case, the two external limit gauges must be smaller than their corresponding internal gauges by an amount at least equal to the given minimum amount of clearance. Let it be assumed that the clearance is to be at least .001 inch, and that the shaft and hole may vary .001 inch from the true dimension, which is 1 inch. Since the hole is to have the nominal dimension and the permissible variation is .001 inch, the dimensions of the internal limit gauge are .9995 inch and 1.0005 inches. Since the clearance between the shaft and hole is to be at least .001 inch, the large end of the external limit gauge will be .9985 inch, and since a variation of .001 inch is permissible, the small end of the external limit gauge will be .9975 inch.

59. Distinguishing Marks for Limit Gauges.—It is well to stamp the size on all the gauges and the words "go in" on the smaller plug gauge and larger ring gauge; on the larger plug gauge and smaller ring gauge may be stamped the words "not go in." Another plan of distinguishing between the larger and the smaller gauges that will save the operator the time required to read the size and words, is to make the handles of the plug gauges and the outside of the ring gauges of different form. Thus, the handle of the larger plug gauge and the outside of the smaller ring gauge may be fluted with semi-circular flutes, while the handle of the smaller plug gauge and the outside of the larger ring gauge may be nurled with a coarse nurling tool. By this distinction, the operator that uses the limit gauges will quickly discover that fluting

stands for "not go in" and nurling for "go in." While this may appear like a small matter on first thought, it should

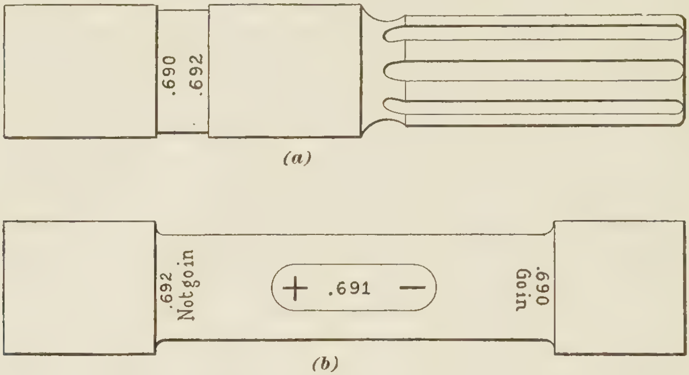


FIG. 32

be remembered that careful attention to such small details will increase the output of a machine operator.

60. A handy method of constructing a *cylindrical plug limit gauge* is shown in Fig. 32 (*a*). Here the plug gauge is made

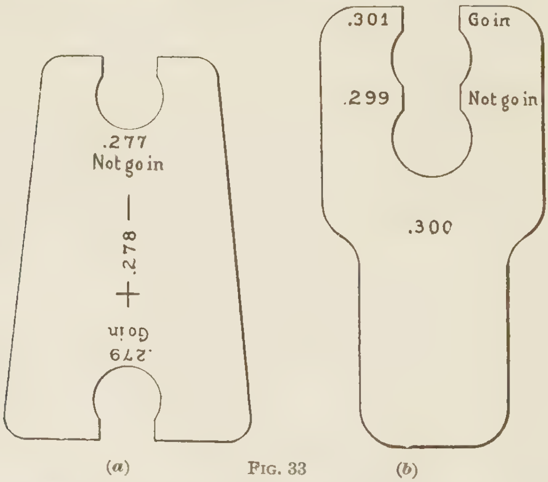


FIG. 33

of two different diameters separated by a neck of ample size. The difference in the two diameters is equal to the allowable

limit of variation. Evidently, if this gauge is used, the operator can gauge a hole faster than when two separate gauges are employed. A somewhat different plug limit gauge is shown in (*b*). Here the gauges are at the ends and the handle is between them. The larger, or "not-go-in," gauge is made longer than the smaller gauge, so that one look will be sufficient to inform the operator which end is the larger. As it seems natural to assume that the longer end is the larger in diameter, it is recommended that it be made thus.

61. A *caliper limit gauge* may be formed with an opening at each end, as shown in Fig. 33 (*a*). It is a good idea to shape the ends of the gauge differently, in order to make a distinction between the large and small opening; thus, the gauge may taper on the outside, being largest at the end that has the larger opening. A caliper limit gauge may often be made advantageously of the form shown in Fig. 33 (*b*). If thus made, the work can be gauged without reversing the gauge, thus effecting a saving of time and effort on the part of the operator.

ANGULAR GAUGES

GRINDING AND LAPPING FLAT GAUGE SURFACES

62. Distortion of Flat Surfaces by Grinding.—Work whose surface is to be ground plane may be held to the grinding fixture by shellac, by soldering it to the fixture in spots along the edges; by special fixtures, or by a magnetic chuck.

Light cuts, say .001 inch, must be taken to overcome the distortion caused by the intense surface heat while grinding. The work, heated by grinding, will be chilled instantly after grinding, causing a contraction of the surface that expanded with the heat. The deeper the cut, the deeper will be the distortion. This distortion is sometimes the cause of the alteration of finished surfaces and dimensions.

In general, the surface that is ground will be concave; whereas, the bottom, or holding, surface will be convex, owing to the

grinding action. If both sides are ground on a true chuck, the concave and convex surfaces will usually be parallel.

This action is not limited to thin work, but takes place in very thick cross-sections. A $1'' \times 1\frac{1}{2}'' \times 4''$ piece of hardened steel or cast iron, if ground on the 1- or $1\frac{1}{2}$-inch surface, will be .001 inch or more out of plane. A few light blows on the concave surface with a hammer that has a slightly rounded face will straighten out the surface.

63. Allowance and Wheels for Grinding Flat-Surface Gauges.—The amount of metal to allow for grinding after hardening the gauge depends on how much the piece is liable to be distorted on account of its shape, thickness, length, and contour. A gauge .005 in. $\times \frac{1}{2}$ in. $\times$ 3 in. would have to be not less than .016 inch thick after hardening; whereas, a gauge $\frac{1}{2}$ in. $\times \frac{1}{2}$ in. $\times$ 3 in. would require only a grinding allowance of .003 inch on a side. For grinding hardened steel and cast iron, as well as for general finishing, a wheel of No. 46 grain and rather soft grade will give good results. For grinding high-speed steel, a softer wheel is required. If there is doubt about the grade and grain of wheel to use, a wheel having the softer grade and coarser grain should be selected. If the grinding operation is started with too hard a wheel, its glazing action will very likely spoil the gauge.

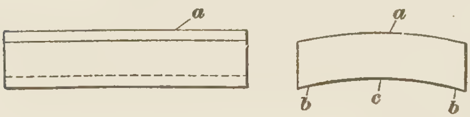


Fig. 34

64. Flat-Surface Lapping.—Peening a surface causes it to curl or to assume a convex shape. The same effect is produced by lapping; consequently, a surface made convex by lapping may be returned to its original shape by peening the opposite side. As a lapped surface will curl more than the allowance left for finishing, it must be straightened. Fig. 34 shows, somewhat exaggerated, the form that a piece of work originally surrounded by nearly plane surfaces will assume when lapped on the surface a. When this piece of work is lapped on the opposite side, the ends b are the surfaces that come in contact with the lap and are reduced first; when the

center is reached the work will be curled in the opposite direction and the surface c will become convex.

When a piece of work is to be lapped plane on opposite sides, as a and c, Fig. 34, the last surface ground, which will be found to be slightly concave, should be the first surface lapped. Both surfaces should be frequently tested with a straightedge and the thickness of the piece in the center should also be noted. The surface opposite the one being lapped must be kept straight, or within the final finish measurement, by peening it lightly with a polished rounded hammer face. When peening a surface, the work should be started in the center and continued gradually to the ends, peening from side to side.

65. Sometimes the work must be lapped on one surface only, a grinding finish being satisfactory on the opposite surface. In such a case, one surface is lapped, the corner of the lap being used to insure the lapping of the central part of the piece. When the work is lapped on thus, the central part receives the greatest pressure and contact with the lap. Lapping in this way will produce a concave surface that is reduced to a plane by working toward the center of the lap.

On testing the opposite surface with a knife-edge straightedge, it will be found to be concave, for which reason it should be reground. After regrinding, the lapped surface will be convex and the ground surface concave. The ground surface is then peened lightly until the lapped surface tests plane. Instead of finishing by peening, the ground surface may be lapped lightly, which operation gives the same effect. Finishing in this way will leave a poor appearance unless the surface defects are covered up by frosting with an oilstone.

66. In order that work may be finished to a true plane surface, a lap having a true plane surface is required. A soft, close-grained, well-annealed, solid, cast-iron lap about $2\frac{1}{2}$ in. $\times$ 7 in. $\times$ 10 in. makes a well-proportioned and very good lap. It can be reground on most surface grinders. The surface is finished smooth, without checks or creases.

The lap is proved by the three-surface axiom, which is, *three surfaces cannot fit one another unless all three are plane.* The

proving of a lap and a straightedge is explained later under the heading Straightedges and Flat-Surface Laps.

67. Charging Flat-Surface Laps.—For rough lapping a roll, a flat cast-iron block, or a hard, flat piece of steel may be used to crush and embed the abrasive into a lap. A roll is preferable to either of the charging blocks to charge a cast-iron roughing lap; whereas, the charging blocks are better to charge a Babbitt or a lead lap, as the weight of the roll would compress the soft metal at the corners and edges and cause the lap to become convex. A coarse grade of abrasive is used. The pressure crumbles the abrasive, causing it to expel the old charge and present new cutting points; the dislodgment of the old abrasive allows the new charge to embed itself in the exposed surface.

68. For finishing the lapping operation, 10- or 15-minute carborundum or its equivalent is used. A thin coating of sperm or kerosene oil is spread over the surface of the lap before charging it. A roll of cloth covered with the abrasive and oil is employed for charging the lap. When mixing the abrasive and oil, enough gasoline is used to distribute them uniformly. The gasoline will evaporate instantly, causing the formation of a thin layer of oil, which prevents the formation of *glaze spots*, or *birds' eyes*.

If there is too much oil or abrasive, the piece that is being lapped will act as a plow, causing the edges to become lower than the general surface. When the lap becomes sticky, it is washed clean with gasoline. The amount of stock to allow for lapping depends on the condition in which the grinding equipment leaves the surface and the distortion that is likely to occur when lapping. With a good equipment, .002 inch is enough to leave to free the surface of wheel marks.

TAPER GAUGES

69. Originating Tapers and Angles.—The most accurate way of originating a taper or an angle, except a 60°, 90°, and 180° angle, is by the use of the device shown in Fig. 35.

The principle involved is the same as that used to measure accurately a taper or angle. In originating a taper or an angle gauge, the gauge is ground and lapped so that when tested in the device, the taper or the angle will be shown to be correct.

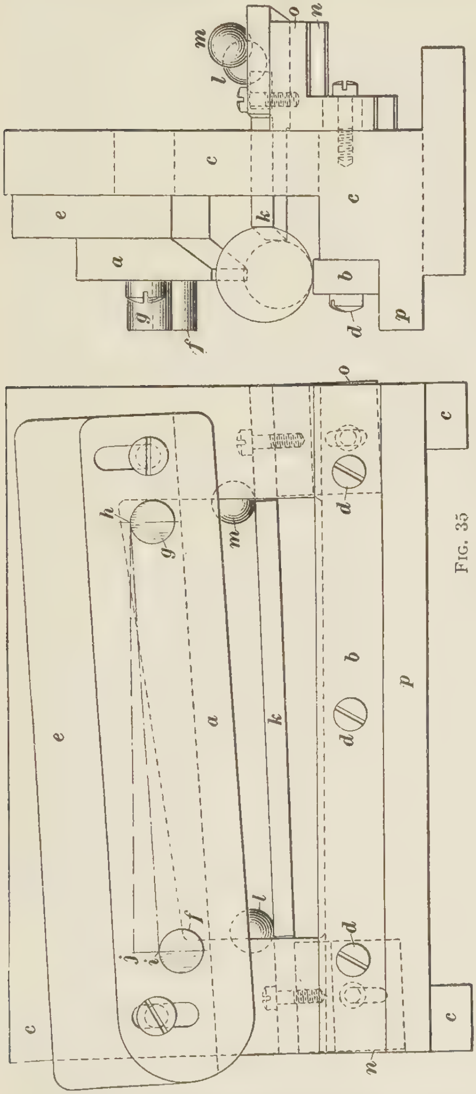


FIG. 35

In Fig. 35, *a* and *b* are two hardened straightedges that are ground and lapped as nearly true as possible, *a* having a working surface of $\frac{1}{8}$ inch and *b* a working surface of $\frac{3}{8}$ inch. The lower straightedge *b* is attached rigidly to the frame *c* by means of the screws *d* and is parallel to the base of the frame. The straightedge *a* and part *e*, which are rigidly connected to each other by screws, not shown, are so mounted on the frame that they can readily be adjusted and locked in position. Two buttons *f* and *g*, which are of equal diameter, truly cylindrical, and of a known and permanent center-to-center distance apart, are attached to the straightedge *a* and at right angles to it.

70. Let the vertical line h, Fig. 35, be drawn through the center of the button g and the vertical line $i\,j$ through the center of the button f. The horizontal line $j\,h$ is then drawn through h, the intersection of the vertical line h with the circumference of the button g, intersecting the vertical line $j\,i$ at j. The $\sin j\,h\,i = \frac{i\,j}{i\,h}$. But the distance $i\,h$ is equal to the known center-to-center distance between the buttons f and g, and the distance $i\,j$ is the distance of the button g above the button f. This distance, $i\,j$, may be measured with a height gauge or a micrometer caliper. Therefore, by dividing the distance $i\,j$ by the distance $i\,h$, the sine of the angle $j\,h\,i$ is obtained. By referring to a table of sines, the angle corresponding to the sine is found. The angle between the straightedges is equal to this angle.

EXAMPLE.—The center-to-center distance between the buttons, Fig. 35, is 5 inches and the button g is .5 inch higher than the button f. What is the angle made by the straightedge a with the straightedge b?

SOLUTION.—In this case, $i\,j$, Fig. 35, equals .5 in. and $i\,h$ equals 5 in. Hence, $\sin j\,h\,i = \frac{.5}{5} = .1$, and the angle $j\,h\,i$, referring to a table of natural sines, is $5° 44'$. The angle between the straightedges is $5° 44'$. Ans.

71. To originate an angle with the device shown in Fig. 35, multiply the sine of the angle required by the known center-to-center distance between the buttons f and g. The result obtained will be the distance the button g is to be set higher than the button f. The buttons may readily be set to this difference in height with a height gauge or with a micrometer caliper measuring from the base of the frame.

Let it be required to set the device to a 30° angle, the known center-to-center distance between the buttons being 5 inches. $\sin 30° = .5$; this multiplied by 5 gives $2\frac{1}{2}$ inches as the distance that button g is to be set higher than the button f.

The angle of conical gauges is generally expressed as an included taper, in inches, to the foot. To originate an included taper with the device shown in Fig. 35, the given taper is reduced to inches to the inch and the result is multiplied by the center-to-center distance between the buttons f and g. The result

thus found will be the distance that the button g is to be set higher than the button f.

Example.—The Brown & Sharpe No. 12 taper is $\frac{1}{2}$ inch to the foot. To originate this taper, how much should the button g be set higher than the button f, if the center-to-center distance between the buttons is 5 inches?

Solution.—By dividing $\frac{1}{2}$ in. by 12, the taper is found to be .04166 in. to the inch; then, by multiplying .04166 by 5, the distance that the button g is to be set higher than the button f is found to be .2083 in. Ans.

72. When measuring tapers or angles with the gauge shown in Fig. 35, care must be taken to have the line of contact of the work and gauge at right angles to the buttons f and g, that is, parallel to the straightedges. The necessity for this precaution can readily be demonstrated by fitting a 60° thread gauge to say, a 45° angle by tilting the gauge to one side.

To assist in placing the work properly, there is sometimes provided a back straightedge k, Fig. 35, having a working edge of $\frac{1}{4}$ inch and two $\frac{1}{2}$-inch balls l and m soldered to it the same center-to-center distance apart as the buttons f and g. These balls are placed equally distant from the working edge of k and the straightedge is mounted on the adjustable brackets n and o. The ball l should be set nearer the straightedges a and b by an amount equal to one-half the distance the button g is set higher than the button f. To set the balls, the device is supported on a surface plate with the projection p and the buttons f and g resting on it, the length of the buttons and the projection p being such that when supported on them the faces of the straightedges a and b will be parallel with the supporting surface. The necessary measurements to set the straightedge accurately are made with a height gauge and are taken from the face of the straightedge a.

73. Originating Angular Gauges.—Angular gauges are originated by grinding them on a swiveling magnetic chuck a, Fig. 36, provided with the measuring buttons b and c. These buttons are of equal diameter, in this case $\frac{1}{2}$ inch; truly cylindrical; parallel with the pivot d, of which button b is the head; and of a known center-to-center distance apart, in this case 3 inches. The bottom of the base e must be plane and parallel

with the pivot; and the top of the swinging leaf f must be parallel with the pivot and equally distant from the buttons. The face g of the support h must be parallel with the pivot and at right angles to the face of the leaf f. After finishing the surfaces i and j of the gauge k parallel to each other and roughing the edge l approximately to size, the gauge is placed on the chuck as shown.

74. Let the line $m\,n$ be drawn joining the centers of the buttons and the horizontal line $n\,o$ intersecting the vertical line through m at o. Then, the angle $p\,q\,r$ equals the angle $n\,m\,o$, which has for its cosine $\frac{m\,o}{m\,n}$. Hence, the distance that the button c must be set above the button b equals $m\,o$; that is, $m\,n$, the known center-to-center distance between the buttons, multiplied by the cosine of the angle to be originated. A height gauge is used to set the buttons, and a cup wheel s is employed to grind the surface l.

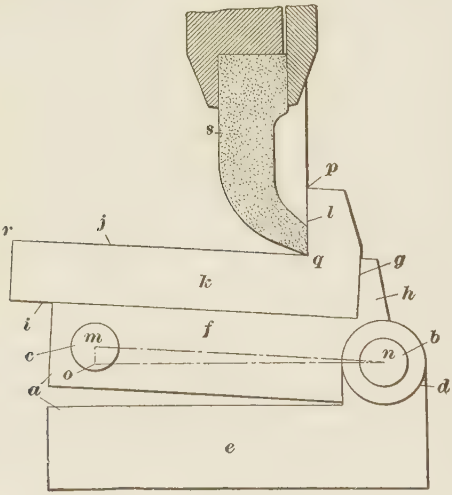


Fig. 36

Example.—How far must the button c be set above the button b when originating an 85° angle, the center-to-center distance between the buttons being 3 inches?

Solution.—The cosine of 85° is .0872. Hence, the required distance is $3 \times .0872 = .2616$ in., nearly. Ans.

75. Originating a 60° Angle.—A 60° angle can be originated most readily by constructing an equilateral triangle, each interior angle of which is equal to 60°. Three bars are made, as a, b, and c, Fig. 37, exactly alike and with the holes the same distance apart on the center lines. These bars when connected by pins passing through the holes will form an

equilateral triangle; and, as the edges of the bars are parallel to their center lines, the angles formed by the edges of the bars will be 60° angles.

The flat sides of the pieces are first roughed nearly to size; the ends are then tongued and slotted and the sides are soldered

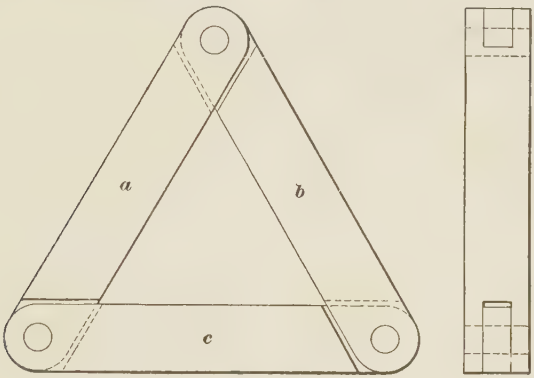


Fig. 37

together. After the holes are finished plugs are fitted in them and the edges are machined and lapped parallel with the center line of the holes. When assembled, the tongues should not touch the sides of the slotted portion, the sides being held in position by the plugs, which are fitted into the holes.

RIGHT-ANGLE GAUGES

76. Originating a 90° Angle.—The following method may be used to originate two 90° angle gauges, both of which, if skilfully made, will be about as correct as it is possible to produce them. One appliance is necessary, however, on the truth of which the correctness of the angle gauges will depend. This appliance may be either a straightedge or a surface plate; either may be used, but it must be as true as skill and ingenuity can make it.

77. Grinding 90° Angle Gauges.—The bottom surfaces of the angle gauges are first ground as nearly plane as possible,

a surface-grinding machine being used for this work. The angle gauges *a* and *b*, Fig. 38, are usually chambered out as shown at *c*. The amount of surface to be finished is thus reduced, the narrow ribs being enough contact surface for testing purposes. The surface plate *d* is sometimes replaced by a knife-edge straightedge.

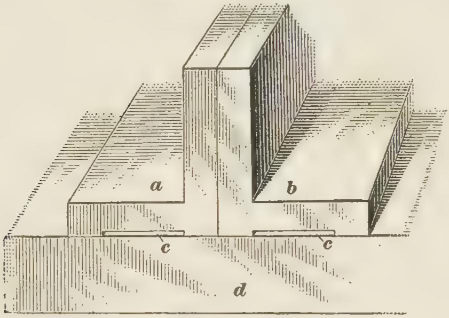


FIG. 38

Pushing and pulling the work, which is fastened to a flat plate, by hand under the wheel of a surface grinder, is the most accurate way of grinding a plane surface. An adjustable knife-edge square, shown in Fig. 39, is used to test whether the gauges are alike. The blade *a* is pivoted at *b* and may be adjusted by means of the screws *c*. After the surfaces of the angle gauges are ground, they are placed on a true surface plate against each other as shown in Fig. 38 and clamped lightly together. If both edges, after having been found to have the same angle by the adjustable knife-edge square test, touch so that no daylight can be seen between them, and all the edges prove straight when tested with a knife-edge straightedge, both angle gauges are 90° and correct.

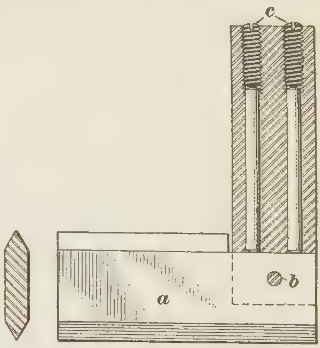


FIG. 39

78. Lapping 90° Angle Gauges.—After the surfaces of the gauges are ground, they are lapped plane and to the correct angle. The lapping operation removes the irregularities occasioned by the width of the feed marks, the vibration of the wheel, dust gathering under the work, and other causes. On account of the bottom surfaces of

the angle gauges being chambered, the side surfaces are first lapped plane and the gauges are finished by lapping the bottom surfaces. Less lapping will then be required.

Though the angles *a* and *b*, Fig. 40 (*a*), are not alike, their sum may be equal to 180°. This error may be detected by setting the adjustable knife-edge square to one of the angles and then testing the other angle with the adjustable square. Should the angles *a* and *b*, in (*b*) and (*c*), be equal, but their sum not be equal to 180°, as shown somewhat exaggerated, a knife-edge straightedge will detect the error, which is caused by the knife-edge square not being set at 90°. If the gauges shown in (*c*) are inverted and placed on a surface plate, they will appear as shown in (*d*). In this case, the knife-edge square is adjusted an amount equal to the estimated half of the error and the gauges are relapped to fit the square. This process is continued until the straightedge test proves the accuracy of the knife-edge-square angle.

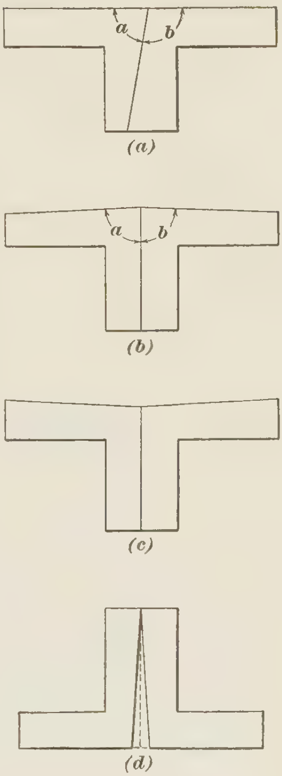


Fig. 40

STRAIGHTEDGES AND FLAT-SURFACE LAPS

79. Straightedges are made in various forms. They are sometimes made rectangular in cross-section and of uniform width throughout their length. They must then be made wide and thick enough to give stiffness sufficient to prevent any sensible deflection with reasonable care in their use.

Straightedges become more sensitive, that is, they will more readily show a minute deviation, as their measuring edge is made narrower. They are most sensitive when made

so that they touch the work merely along a line; that is, when they are in line contact with it instead of in surface contact. Then, carrying out this idea, a straightedge may have sufficient thickness and width in order to give stiffness, and it may be beveled at its measuring edge in order to give sensitiveness. Beveled straightedges are usually beveled sufficiently to leave the measuring edge $\frac{1}{16}$ inch wide. When beveled off still more, the cross-section bears a close resemblance to that of a knife blade, and the straightedge is then called a **knife-edge straightedge.**

80. A cross-section of a very satisfactory knife-edge straightedge is that shown in Fig. 41 (*a*). This form combines stiffness, lightness, and convenience of handling. The more common form is shown in (*b*); it is beveled on both sides to give a narrow edge. In both forms of knife-edge straightedges, the actual testing edge *a* has a semicircular cross-section; in other words, the testing edge, instead of forming a plane surface, forms part of a cylindrical surface. When thus made, they can be held at a slight angle to the work, without in any way interfering with the correctness of the measurement. Hence, they are more easily used than straightedges in which the testing edge forms a plane surface, and which must be held so that the testing surface is in contact all over with the surface to be tested, for if canted over so that one edge of the testing surface is in contact with the work, a wrong indication will be given if that edge should be out of true.

(*a*) Fig. 41 (*b*)

81. As a general rule, in the construction of straightedges with a plane-surface testing edge, little attention is paid to making the bounding edges of the testing surface absolutely straight; this detail would add considerably to the cost without gaining any particular advantage. Besides, the sharp edges would rapidly be worn out of true.

82. Hardening Straightedges.—Straightedges intended for work in the shop are usually hardened on the testing edge and occasionally all over. The object of hardening is to reduce the liability of wear. Since the hardening process sets up severe internal stresses, which are gradually released by the aging of the steel, hardened straightedges will occasionally become crooked and require refitting. If the edge alone is hardened and the back is left soft, this change of shape will, as a general rule, be small enough to be negligible. Straightedges intended for reference only—that is, for testing working straightedges—may be left soft; large straightedges must usually be left soft on account of the difficulty of hardening.

To harden a straightedge on the edge only, clamp it between iron bars, leaving the edge exposed. Heat evenly all over and then quench. The iron bars prevent the water from coming in contact with the back and sides, which are consequently left soft. The temper is next drawn to a purple color for ordinary straightedges and to a dark straw color for knife-edge straightedges; also the edge is straightened while at this heat, owing to the fact that the metal will bend easily when warm. The straightedge is held in a fixture while it is being straightened and tempered, the heat being supplied from a Bunsen burner or other convenient source, and when straight, as determined by the eye, and when the temper is drawn as desired, it is plunged in an oil bath.

83. Originating a Straightedge.—A correct straightedge can be produced either by fitting it to an absolutely correct surface plate, or it can be originated in accordance with the following axiom: *Three straightedges cannot fit one another unless all three are straight.* The facilities at command of the toolmaker will determine which method is to be used.

Three straightedges having been finished all over, one is selected as a trial straightedge, preferably the one that is believed to be most nearly correct. This straightedge is marked *1* and the two others are marked *2* and *3*, respectively. The straightedges *2* and *3* are carefully fitted to *1*, as shown in Fig. 42, until no daylight can be seen between *1* and *2* and *1* and *3* when

they are held up against a strong light. Straightedges *2* and *3* are next placed together, as shown in the illustration. Any deviation from a straight line will now be shown double. The error of one of these two equal straightedges, say *2*, is now reduced and this straightedge is used as a trial one, to which *1* and *3* are fitted. Straightedges *1* and *3* are then placed together and the error observed; the error of straightedge *3* is reduced and straightedges *1* and *2* are fitted to it. Straightedges *1* and *2* are now placed together, the error of *1* is reduced and it is used

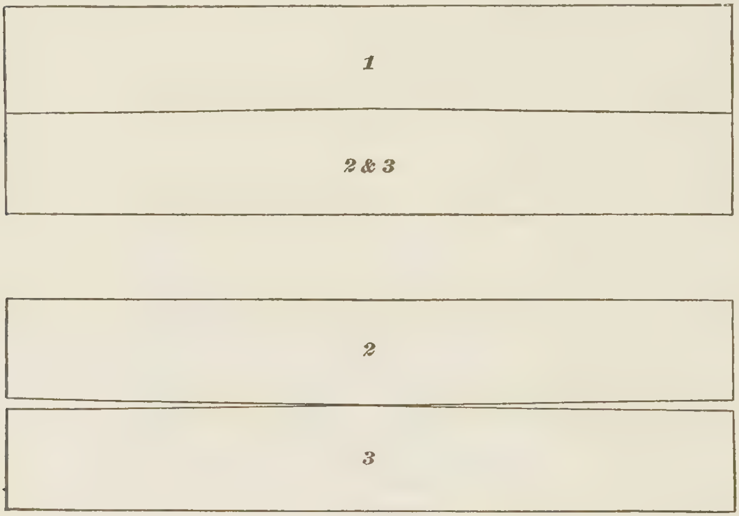


FIG. 42

as a trial straightedge, to which *2* and *3* are fitted. These operations are repeated until all three straightedges fit one another; all three will then be straight.

It is not possible to use fewer than three straightedges, since two straightedges can be perfectly fitted to each other and be a perfect fit on each other in any position in which they are placed, without being anywhere near true.

84. **Originating a Knife-Edge Straightedge.**—Knife-edge straightedges cannot be very readily originated by making three fit one another, as it is practically impossible to hold two of them together so as to be in contact all along. On account

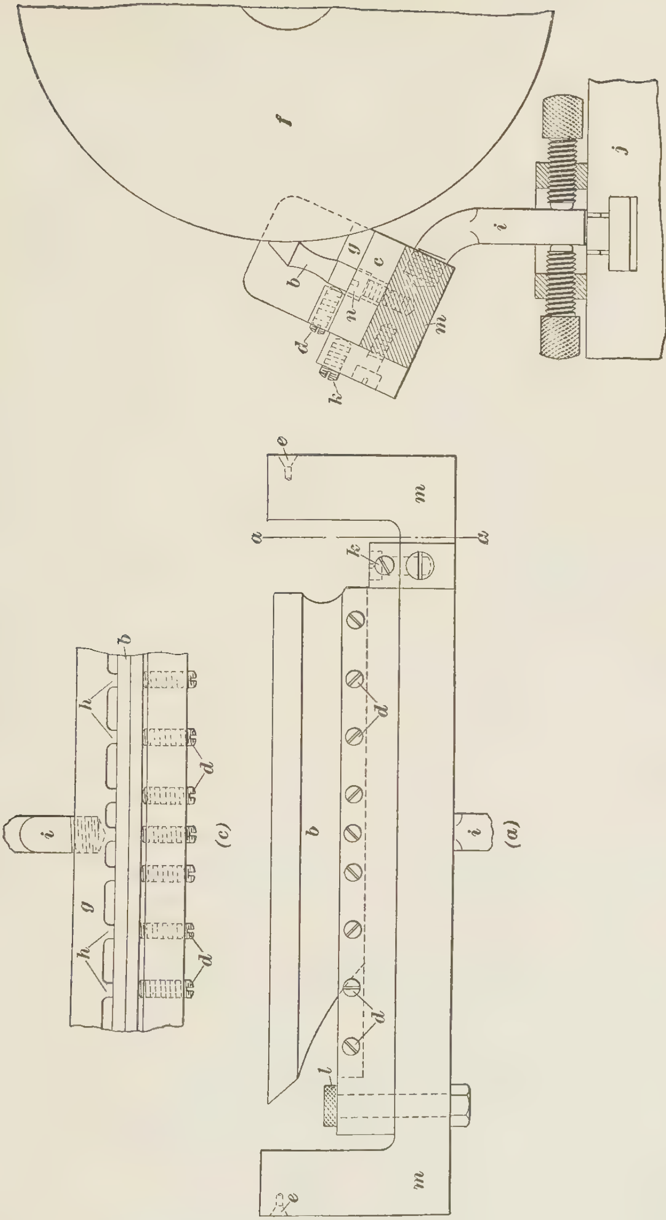


Fig. 43

of this difficulty, knife-edge straightedges are usually fitted to an accurate surface plate, or to a glass *test bar;* that is, to a glass straightedge having a plane-surface testing edge.

85. Grinding Knife-Edge Straightedges.—One method of grinding a knife-edge straightedge is shown in Fig. 43; view (*b*) is a cross-section of (*a*) at *a a*, and view (*c*) is a portion of the top view of the fixture and straightedge. The straightedge *b* is held in the adjustable edge holder *c* by the binding screws *d* and the fixture is centered at *e* to receive the centers of the grinding machine. Using plenty of water to keep the heat, which causes distortion, down to a minimum, and a free cutting wheel *f*, the sides of the straightedge are ground slightly concave. In order to reduce distortion, and consequently the lapping of the edge to a minimum, the back part *g* of the holder *c* is chambered out as shown in (*c*), so that the straightedge will be supported on one side by the binding screws and on the other side by the projections *h* opposite the screws. All the binding screws are set about $\frac{3}{4}$ inch apart, except those in the center, which are placed close enough together to hold the smallest straightedge likely to be ground.

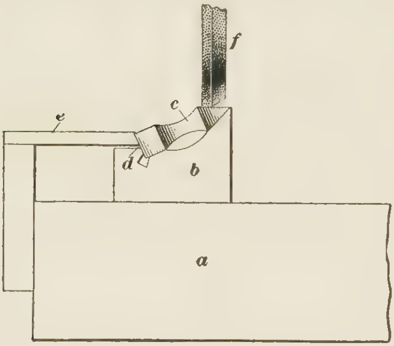


FIG. 44

An arm *i*, view (*b*), $\frac{1}{2}$ inch in diameter and long enough to reach to the bed *j* of the machine to which it is clamped, is provided to steady the fixture. By means of the screw *k*, the holder *c*, which is pivoted at *l* by the pin shown, may be adjusted as needed to grind the working edge of the straightedge parallel with the opposite side. The holder *c* is then clamped to the body *m* of the fixture by the screw *n*.

86. Knife-edge straightedges may be ground on a surface grinder, but, owing to the distortion of the edge, not so satis-

factorily as by the method just described. If a magnetic chuck *a*, Fig. 44, is employed, a piece of cast iron *b* is planed out to fit approximately the sides of the straightedge *c*, and the back edge *d* of the straightedge is used for the contact with the pole *e*, which serves to complete the magnetic circuit. The wheel *f* is narrowed on its face to avoid vibration and the edges of the straightedge are ground flat.

For a temporary fixture, a piece of $1\frac{1}{4}$-inch round iron may be centered and slotted. The straightedge is soldered in the slot, and, when grinding, the taper movement of the machine is used to adjust the machine to grind the sides parallel. The back and working edges need not be exactly parallel. The knife-edge straightedge is then finished as previously directed, or it may be finished along with a bevel-edge straightedge and surface lap, as explained later.

87. Planing and Grinding Flat-Surface Laps.—Flat-surface laps are usually made in pairs. If the lap is machined on a planer, the surface will be a little concave, owing to the wear that takes place on the planer crosshead. Similarly, when the lap is ground on the surface grinder, the surface will be a little concave, owing to strains being set up in the ground surface. No strains are present in the planed surfaces, as the stresses are relieved by the use of the planing tool, though the surface is left in a loose, crumbly condition.

The ridges on a planed surface are more pronounced than those on a ground surface, while the strains in a ground surface are greater than those in a planed surface. Lapping a surface causes it to assume a convex shape. This fact is a great help in finishing a lap surface to a true plane, since, the ground surface being concave, the amount of metal to be removed is reduced.

88. Lapping Flat-Surface Laps.—The laps are next placed with the abrasive, which is No. 120 carborundum or its equivalent, between the concave surfaces and partly rotated with a sweeping motion. One of the laps is occasionally reversed end for end to equalize the wear and contact and the operation is repeated. The strains caused by grinding are thus released or the feed ridges caused by planing are reduced.

This lapping is rather slight, as the abrasive has the effect of many peening points, which, with the releasing of the strain, are liable to cause the lap to become convex. In subsequent lapping processes, 5-minute carborundum, a finer abrasive, is used, if the surfaces are not out very much.

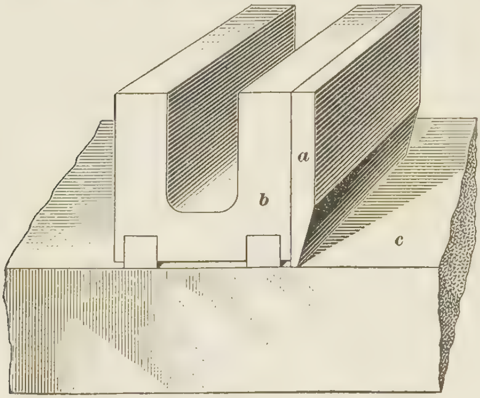


FIG. 45

89. Originating Flat Surfaces and Bevel- and Knife-Edge Straightedges.—The laps, a bevel-edge straightedge *a*, Fig. 45, and the knife-edge straightedge are next finished by lapping until they fit each other perfectly. The square lapping fixture *b* is employed to guide the beveled straightedge on the lap surface *c*, the entire lap surface being used.

The knife-edge straightedge is next stoned slightly concave and lapped on the same lap as was used for the beveled straightedge. The square lapping fixture is not employed, as the edge is lapped rounding each stroke.

When sure that both straightedges are the opposite of the lap, they are compared as shown in Fig. 46, in which *a* is the beveled straightedge; *b*, the knife-edge straightedge; *c*, a wooden

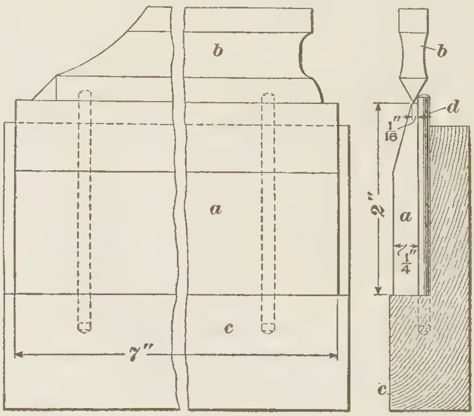


FIG. 46

holder; and *d*, steadying pins. If light shows at the center when the edges are relapped, the lap is convex; if at the ends, the lap is concave. Both laps are tried in this way. The lap that shows convex is probably made of the hardest iron and should be reground, as regrinding is the quickest way to overcome this convexity. The lap made of the hardest iron will probably be the first to be finished flat, as the softer lap is used to carry the abrasive.

90. The abrasive, which is mixed with kerosene, is applied with a brush, around the edges of the lap and the softer lap is kept free from abrasive in the center. A concave lap will produce a plane surface if the edge receives a sweeping motion and is not rotated in a circle, provided the surface surrounding the depression is sufficient to maintain the edge on the lap. The laps are worked and tested in this way until the two straightedges shut out light every time they are tested together. As the straightedges are the opposite of the lap surface, they are now straight and the lap is a plane surface.

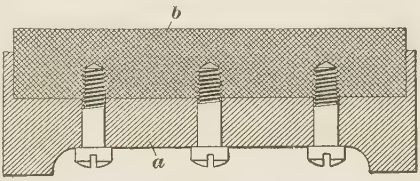


FIG. 47

91. Retruing Flat-Surface Laps.—As the central portion of the lap is most used, this part becomes lower than the edges and corners. A lap consisting of a cast-iron block *a*, Fig. 47, filled with hard Babbitt or lead *b* is used for retruing the lap. Before pouring the Babbitt, the screws that hold it firmly in position should be well coated with graphite, to prevent the metal from sticking to them. These laps are scraped to fit a true surface plate; their surface area is about 50 per cent. greater than the lap to be retrued. When retruing a lap, which has been cleaned with gasoline and freed from abrasive, 5-minute carborundum and plenty of kerosene are applied with a sweeping rotary motion. Babbitt or lead laps are not desirable for knife-edge work, as they are easily scraped out of true.

SPECIAL GAUGES

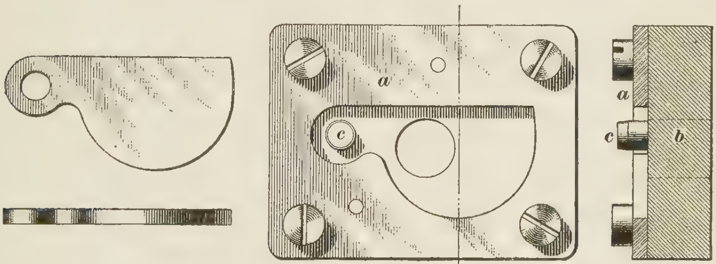
92. Field of Special Gauges.—Where a large number of pieces are to be made interchangeable, this quality can only be preserved by *limit gauges* so constructed as to caliper the piece in all essential directions. In some cases, one set of limit gauges will be sufficient; in others, two or more sets may be required owing to the difficulty, if not impossibility, of gauging the work all over in one operation. Because of the infinite number of shapes possible, no definite rules can be given as to the construction of special gauges; each case must be treated on its own merits and the toolmaker must exercise his ingenuity as to the best way of designing and constructing the gauges. The only general directions that can be given are to make the gauges as simple, durable, and capable of exact duplication as circumstances will permit. Furthermore, means should always be provided for getting the work out of the gauge, or the gauge away from the work without ruining the gauge, in case the work should stick.

93. A few special cases of gauge making follow; the gauges shown and the remarks made in regard to them are intended only as suggestions of how a gauge may be made for the pieces of work shown. The way in which the gauges are made is not necessarily, in each instance, the best method of construction possible and the only one applicable. Circumstances alter cases; while a gauge designed as shown may be eminently suitable for one set of conditions, it may be either too refined or not refined enough for other conditions and requirements.

94. Example of Special Gauge.—In Fig. 48 (*a*) is shown a rather simple piece of work, which is finished on the edges in a profiling machine and has a hole through one end. The sides are to be parallel and the work of an even thickness. It is required to gauge the shape in relation to the hole; it is also essential that the hole and the thickness be correct. To gauge the hole, a cylindrical limit gauge may be employed; for the thickness, a limit snap gauge is best adapted; for gauging the

shape, a gauge may be made as shown in (*b*). The gauge consists essentially of a flat plate *a* that contains a hole of the same shape and size as the work. This plate is mounted on a block *b*, which carries the pin *c* and the latter serves to locate the work properly in the gauge. The pin is made of the minimum size allowable for the hole in the work. Then, if the work is placed over the pin and if it drops into the hole in the plate *a* it is known that the shape of the piece is not over the size.

95. The degree of accuracy with which the work fits into the gauge is determined by inspection. While the gauge shown determines whether the piece of work will go into place or not when the machine or device for which it is intended is assembled, it does not determine whether the piece of work is too small to



(*a*) Fig. 48 (*b*)

perform its allotted function satisfactorily. But if another gauge is made similar to that shown in Fig. 48 (*b*), preferably on the same block, and if this second gauge is made slightly below the minimum size permissible, a limit gauge would be obtained. In this case, if the work enters the smaller gauge, it is proved to be too small; if it cannot enter the larger gauge, it is shown to be too large; but if it can enter the large gauge and cannot enter the small one, it is correct in size within the amount of variation existing between the large and the small gauge.

In order that the work may readily be removed from the gauge, a large hole may be drilled through the block *b*, as shown in the illustration. The work is then pushed out of the gauge either with the fingers or with a small wooden or metallic rod.

96. Example of Special Limit Gauge.—A somewhat different case of gauging is shown in Fig. 49. In this instance, the object of gauging is to determine whether the center-to-center distance *a* of the holes is correct within the predeter-

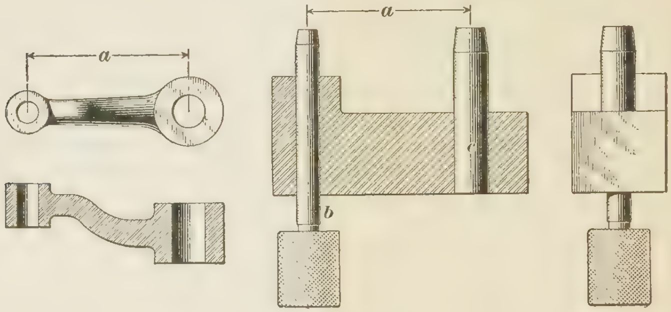


FIG. 49

mined limit of variation. The simplest gauge for this work is a plate with two fixed gauge pins of correct diameter placed the required distance apart. If the pins happen to fit the holes in the work rather closely, it is quite difficult to remove the work from the pins after the work has been forced on, since it is not an easy job to draw the work off squarely. This objection can be overcome by making one of the pins, as *b*, movable; it is then to be made a good sliding fit in the body of the gauge. The other pin, as *c*, is rigidly fixed. Withdrawing the movable pin allows the work to be readily drawn off the fixed gauge pin.

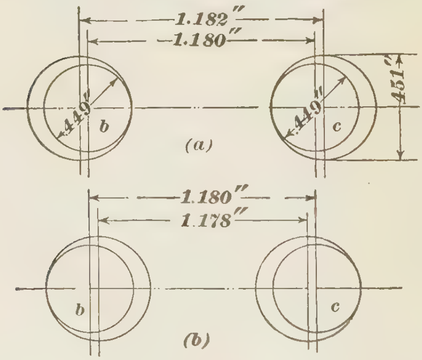


FIG. 50

97. Limit of Variation in Special Gauges.—A pin gauge of the construction shown in Fig. 49 apparently can be used at the same time as a limit gauge. Referring to Fig. 50, let *b* and *c* be the gauge pins and let them be placed 1.18 inches from center to center; also,

let it be assumed that the holes in the work, by previous gauging, have been proved to be larger than .449 and smaller than .451 inch. Then, the gauge pins must be made small enough to enter the holes when their size is the smallest permissible, that is, .449 inch. Now, assuming that the holes are larger, say .451 inch, the work will go over the gauge when the side of the holes touches the inside of the gauge pins, as in (*a*), or the outside of the gauge pins, as in (*b*), and also when the center-to-center distance, for the size of hole assumed, varies between these two extreme positions.

98. In the first extreme position, the center-to-center distance will be 1.182 inches; in the other, it will be 1.178 inches. The extreme limit of variation, 1.182 inches − 1.178 inches = .004 inch, is thus obtained or, as the limit of variation in the size of the holes is .451 inch − .449 inch = .002 inch, a variation double that which is permitted in the size of the holes.

The holes in the work may happen to be the same size as the gauge pins. In that case, the work will not enter at all unless the center-to-center distance of the holes coincides with that of the guide pins. If it varies but .001 inch from it, the gauge will not go into the holes; the work may thus appear worthless when in reality the holes may be located quite within the permissible limit of variation.

99. Now, suppose that the gauge pins are made smaller than the smallest size of hole permissible, say .002 inch, thus making their diameter .447 inch. Then, if they are placed 1.18 inches from center to center, the work will go over the pins if the center-to-center distance of the holes varies between 1.178 and 1.182 inches, if the holes are of the smallest permissible size. If, however, they are of the largest size allowable, as .451 inch, the work will go over the gauge pins if the center-to-center distance varies between 1.176 and 1.184 inches.

100. Having proved that reducing the diameter of the gauge pins results in an increase of the range of variation within which the work will pass over the gauge pins, it is now in order to investigate how this range can be reduced.

The most obvious way is to reduce the limit of variation in the size of the holes. Suppose that the holes are nominally .45 inch in diameter, their limiting sizes are then placed at .4495 and .4505 inch. If the holes are small, say below 1 inch, there is little difficulty in reaming them within this limit. Then, if the gauge pins are made .0005 inch below the smallest permissible size of hole, or $.4495-.0005=.449$ inch, the work will go over the pins if the center-to-center distance of the holes in the work varies between the limits of 1.1785 and 1.1815 inches; that is, if it varies .0015 inch either way from the nominal center-to-center distance.

101. The limit of variation in the center-to-center distance of the holes that can be detected by the use of a pin gauge can be further reduced by constructing one of the pins, preferably the fixed pin, in such a manner that it can be centrally expanded to fit the hole in the work. If this is done, the limit of variation in the center-to-center distance within which the work will go on the gauge will be reduced to one-half of that obtained otherwise.

A satisfactory way that may be suggested for gauging the center-to-center distance of holes is to make both pins adjustable to the size of the hole; one pin is then rigidly fixed and the other is mounted on a slide provided with a vernier that reads to zero when the center-to-center distance is correct. If the work is placed over the pins and both pins are then expanded to fit the holes, the amount that their center-to-center distance differs from the nominal distance is then read off directly by the aid of the vernier. Such a gauge is rather expensive; the circumstances of each case must determine if the investment is advisable.

JIGS AND FIXTURES

DESCRIPTION AND USES

GENERAL DISCUSSION

1. In a general way, the distinction between a *jig* and a *fixture* is not very clear. However, in the manufacture of duplicate parts, **jigs** are commonly accepted as those special devices which are used to guide cutting tools and support the work in such a manner that the work produced by their use becomes alike in all essential features, independently of the skill of the operator; whereas, **fixtures** are those devices which support the work but do not guide the cutting tools.

2. Jigs are used chiefly for the production of holes by drilling, reaming, or tapping, or to support the work for turning, boring, milling, planing, shaping, filing, babbitting, or assembling, and they are called *drilling jigs*, *tapping jigs*, *reaming jigs*, etc., according to the operation for which they are used; or, in cases where the same jigs are used for different operations, they are called *combination jigs*. Among the fixtures that are often called jigs are boring, turning, milling, filing, assembling, and babbitting fixtures.

3. All jigs consist of certain essential parts, which are: the *guides* for the cutting tools; the *body*, which supports the guides and the work; the *stops*, or *gauges*, which locate the work correctly in reference to the guides and to one or more points or surfaces of the work; the *clamping arrangement*, which serves

to hold the work to the body; and the *supporting surface* or surfaces, which rest on the table of the machine and insure parallelism of the axes of the guides with the axis of the spindle that carries the cutting tool.

4. The clamping arrangement and the supporting surface do not necessarily form an integral part of the jig, but may be separate therefrom. Thus, in some cases, the jig and the work may be held together by **C** clamps or machinists' clamps; likewise, the supporting surface may be some suitable part of the work itself. In all cases, however, these two features must exist in some form. In drilling, reaming, and tapping jigs, the plane of the supporting surface must be perpendicular to the axis of the guide.

5. Capability of accurate duplication is of prime importance not only when the jig is in constant demand, but also when a number of like jigs are required. In the first case, the wear and the abuse a jig is liable to receive will sooner or later call for its duplication; both in the first and in the second case, an accurate duplication can, in almost all instances, be readily provided for by making the jig or jigs from a master jig preserved for this purpose. This master jig is usually marked with the the same number as the working jig, or jigs, so that it may be readily located when desired.

6. Absence of sharp corners means ease of handling; any feature that makes a tool agreeable to the touch may confidently be expected to reduce the time cost per piece. As jigs are used to reduce the cost of manufacturing, it is desirable that the corners be well-rounded.

Accuracy of the jig itself, while mentioned last, is the most important requirement. It should always be remembered that any inaccuracy of the jig will be duplicated in the work; and if the cutting tools are loosely guided, the errors may enlarge. While accuracy is generally necessary, some jigs do not need to be as accurately made as others. The toolmaker should always aim to obtain essential accuracy; any greater accuracy means an outlay of money that is generally not warranted by the conditions of the case.

FORMS OF JIGS AND FIXTURES

7. Two general types of jigs are in common use, each of which has its own sphere of usefulness. The one type, called the *clamp jig*, is intended for work where the center lines of all holes that are cut by the aid of the jig are parallel. The holes need not necessarily be located in the same plane, nor must they be drilled from the same side of the jig. Jigs of this type frequently resemble some form of a clamp, although in some cases there is little resemblance between the jig and a clamp. The other type of jig is intended for work that requires the holes that are to be cut through it, or into it, to be at various angles to one another. Since jigs intended for holes at angles to one another most frequently resemble some form of a box, the name of *box jig* is commonly applied to them. Combination jigs may be of either the clamp or box type.

CLAMP JIGS

8. Simple Jig.—A form of drilling jig is shown in Fig. 1. It consists simply of a flat plate made of suitable material. The outline of the jig is the same as that of the work; holes are drilled in the jig to serve as guides. The jig is intended to be laid on the work and is then so clamped to it that its outline coincides with that of the work; this is one form of clamp jig. Such a jig is cheap and will serve well for flat work where extreme accuracy in the location of the holes is not essential. When it is to be used only for a few pieces, it may be made of machinery steel and the holes case-hardened. When the holes wear, either a new jig must be made or the holes must be counterbored to receive hardened steel bushings.

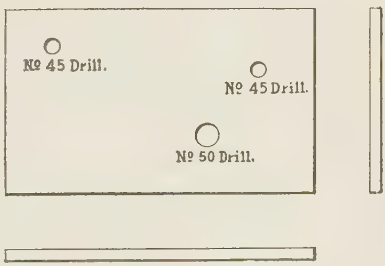


FIG. 1

9. Jig With Hardened Bushings.—In Fig. 2 is shown a jig with hardened bushings. Since such bushings can be replaced easily when worn, the center-to-center distance of their axes can be accurately preserved.

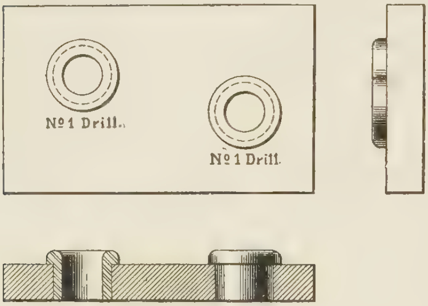


FIG. 2

10. Jig With Hardened Bushings and Stops.—Fig. 3 illustrates a more advanced form of jig, in which stops have been added for the purpose of alining the jig on the work. In this particular instance, the stops are formed by flanges *a* and pins *b* so placed as to suit the outline of the work. If the different pieces of work are quite uniform, as, for instance, if the outline has been finished by profiling, punching, or milling, quite accurate work can be done in a jig of this type. In many instances, it is not even necessary to clamp the work to the jig, as the stops will often be sufficient to prevent shifting.

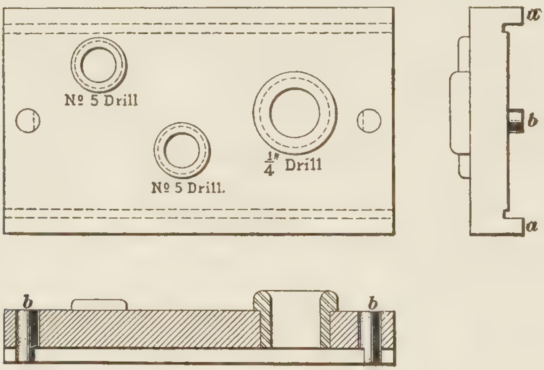


FIG. 3

11. Jigs for Drilling Flanges.—Fig. 4 shows a form of jig well adapted for drilling holes through flanges. The jig

body is recessed to go over the flange and the jig is attached and clamped by means of the hook bolts shown. Attention is called to the relative positions of the hook bolts and the bushings. They should always be so located that neither the head of the hook bolt nor the nut can ever come in the way of the drill, reamer, or tap that is intended to be guided by the bushing.

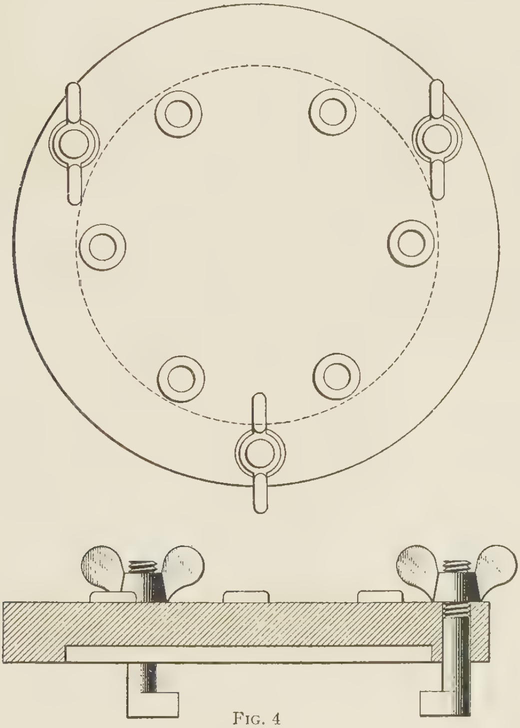


FIG. 4

Jigs of this design are readily modified to be alined to a bored or cored hole in the work by providing the lower surface with a projection of suitable shape instead of the recess shown.

12. Self-Centering Jig.—Fig. 5 shows a form of jig that is largely used for drilling holes in the flanges of work that has a cross-section similar to that shown in the illustration, in which *a* represents the work. The jig body *b* is simply a flat plate

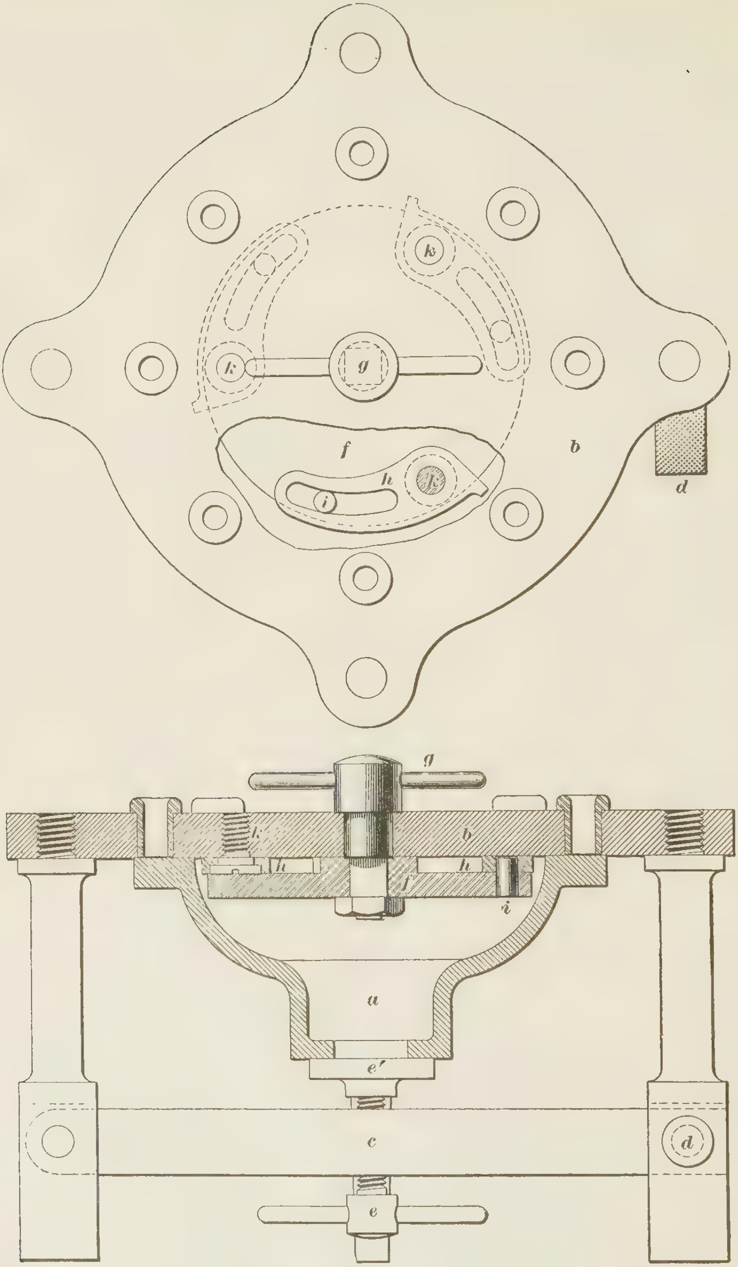


Fig. 5

into which four legs are screwed. Two opposite legs are slotted to receive the yoke *c*, which is hinged at one end and secured in position at the other end by a removable pin *d*. This yoke carries the setscrew *e*, by means of which the work is clamped to the jig. When the work has a hole in line with the setscrew, the latter may terminate in a circular plate, as *e'*. To insert or remove the work, the jig is turned upside down; the pin *d* is then removed and the yoke swung out of the way.

This jig is provided with a self-centering arrangement. Thus, *f* is a plate that can be rotated by means of the handle *g*. This plate carries three pins *i* that enter slots formed in the jaws *h*. These jaws are pivoted to the jig body by screws, as *k*, and their axes are placed nearer the axis of rotation of the plate *f* than the pins *i*. A right-handed rotation of the plate will therefore cause the jaws to swing around their fulcrum screws until they come against the work, which is thus centered. This centering arrangement is not given as the best one that could be devised for all kinds of work, but simply shows one way of centering.

BOX JIGS

13. Drilling Jig for Non-Parallel Holes.—All the jigs so far shown are intended for drilling work in which the axes of all holes are parallel. Fig. 6 shows a box jig designed for drilling holes in three different directions at one setting. The work *a*, which is shown in perspective in (*a*), is to be pierced by the holes *b*, *c*, *d*, and *e*, and is to have the blind hole *f* drilled to a clearance and tapping size. This hole *f* is recessed, as shown, in a separate operation. In the work illustrated, the holes must be located correctly in reference to the two surfaces in contact with the stops of the jig body.

To allow the work to be easily inserted and removed and to give accessibility, the jig is made in two parts, of which the part *g* carries all the bushings and stops, and the legs that form the supporting surfaces. For drilling the hole *d*, the jig is supported on the three legs *h*, the plane of which is perpendicular to the axis of *d*; for drilling the holes *b*, *c*, and *e*, the jig is supported on the legs *i*, and three points of support, as *k*,

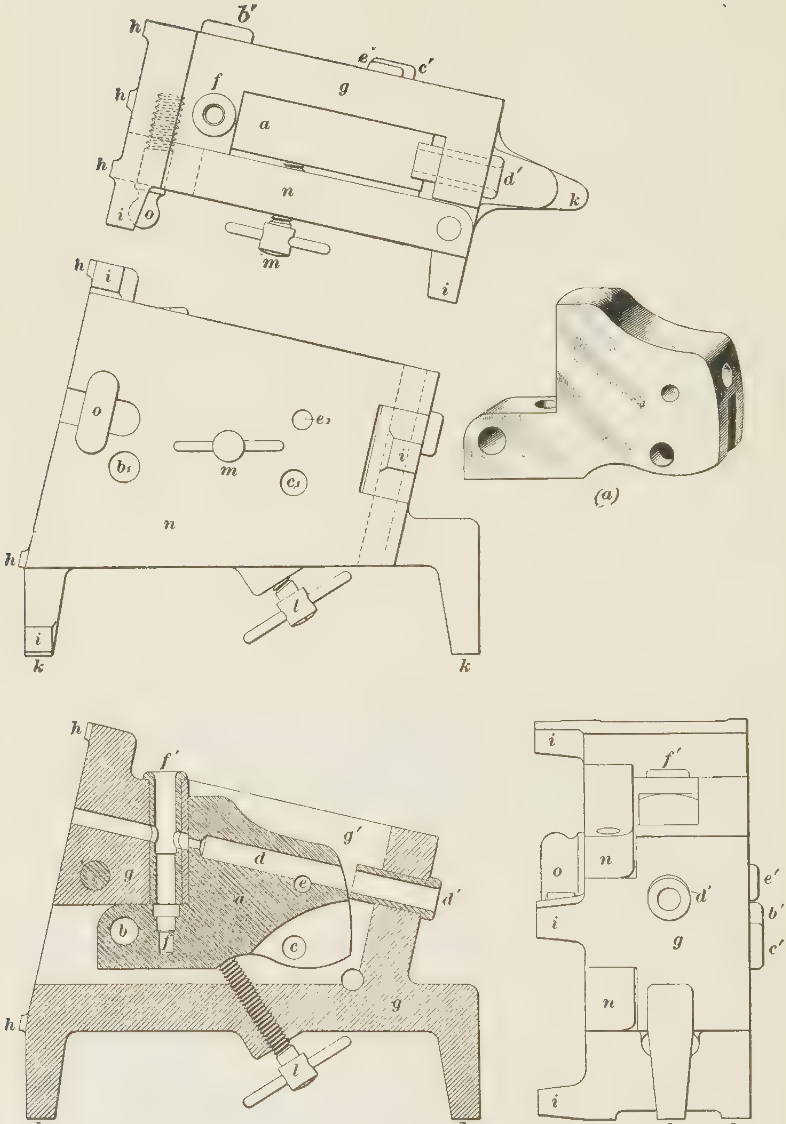


FIG. 6

are provided for drilling the hole f. An examination of the shape of the work shows that it can be held against the stops in two directions by a setscrew l placed as shown; it is held against the surface g' by the setscrew m, which is located in the movable hinged part n of the jig. The part n is clamped by the clamp screw o. The guide bushings for drilling the holes b, c, d, e, and f are shown at b', c', d', e', and f', respectively. As far as the holes d and f are concerned, the holes have two sizes each. The bushings for them are made to the larger sizes, and drilling is continued with smaller drills after the holes have been drilled their large size to the correct depth. The bushing f' is pierced by a clearance hole; since this hole penetrates above the guiding part of the bushing, there is no particular objection to piercing the bushing. Clearance holes as b_1, c_1, and e_1 are drilled through the movable cover in line with the bushings for the escape of chips.

COMBINATION JIGS

14. When work is drilled only, the hole produced is quite rough and usually somewhat larger than the size of the drill, owing to the crowding of the drill and improper grinding. By the use of **combination jigs**, all the holes in the work may be made smooth and to size. The work may be drilled, reamed, counterbored, and tapped at one setting in the jig. A jig for such work is similar in construction to a drilling jig, except that the hole in the jig is first bushed with a hardened lining bushing that is made large enough to receive the removable drilling, reaming, counterboring, and tapping bushings, or the collars supplied for the various cutting tools.

A reamer or a tap will very soon lose its size if its cutting edges are allowed to rub against the sides of a hardened bushing; and if the bushings or collars fit loosely or if their holes fit the cutting tools loosely, a correct center-to-center distance between the holes in the work cannot be obtained.

15. Combination Jig With Removable Bushings. In case removable, or slip, bushings are used, the drilling bushing is inserted first and the hole drilled. The drilling bushing is

then removed and the counterboring, reaming, or tapping bushing is inserted and the hole counterbored, reamed, or tapped. The drilling bushing is made to fit the body of the drill, and the counterboring, reaming, and tapping bushings are made to fit the shanks of the counterbore, reamer, and tap, respectively.

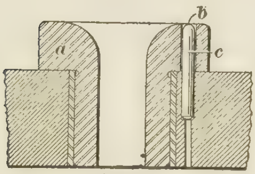


FIG. 7

In order to prevent the bushing from turning in the jig—a necessary precaution—the shoulder *a*, Fig. 7, on the bushing is made wide enough to permit a hole *b* to be drilled through its head. A dowel-pin *c* permanently driven in the jig enters this hole when the bushing is in place in the jig. The circumference of the head of the bushing is nurled, and the head is made high enough to permit it to be grasped between the fingers to assist in removing and inserting it.

16. Combination Jig With Collars.—In Fig. 8 is shown a combination jig that employs collars to guide the cutting tools. The spotting drill *a*, reamer *b*, and counterbore *c* are

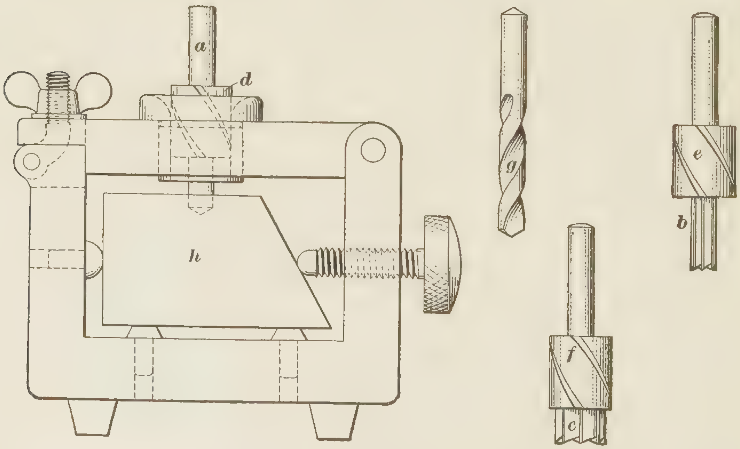


FIG. 8

guided in the bushing by the collars *d*, *e*, and *f*, respectively, which are parts of the tools. In operation, the spotting drill, which is of the same diameter as the twist drill *g*, is used to spot

the hole sufficiently deep to permit the twist drill body to enter at least $\frac{1}{8}$ inch. The hole is then drilled with the ordinary twist drill, which needs only to be guided by the hole made by the spotting drill. The reamer and counterbore are next used to size the hole, being guided and held in alinement by their collars *e* and *f*. If the work is to be tapped in the jig, the tap would be guided in a similar way. Sometimes the cutting tools are guided in the bushing by their own shanks, which are usually larger, or may be made larger, than the size of the finished hole. In the illustration, the spot drill *a* is shown in position in the jig after cutting its way into the work *h*.

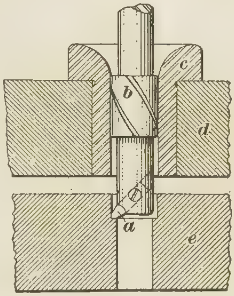


FIG. 9

Oftentimes, the holes are first spotted in the work, the spotting drill being guided in the bushing as before, and then drilled to within a few thousandths of an inch of the size. A *single-point, adjustable boring tool*, guided by a collar as before and as shown in Fig. 9, is then used to finish the hole to size. In this illustration, the boring tool is shown at *a*; the collar, at *b*; the bushing, at *c*; the jig body, at *d*; and the work at *e*.

17. When collars are used to guide reamers or other tools, they generally have several lubricating grooves, preferably spiral, cut lengthwise. These grooves also serve to collect the fine dust and small chips that otherwise would crowd in between the bushing and collar and cause the bushing to cut the collar.

FIXTURES

18. Unless the operator is skilled, accurate work cannot be produced, even with a perfectly made fixture, as neither the size of the hole bored in the work held in a boring jig nor the cut taken by the milling, shaping, planing, or turning tool is regulated by the fixture. The advantage in the use of fixtures lies in the fact that in machining duplicate work each piece is readily held in nearly the same position in the jig as the

preceding pieces. In many cases, by properly adjusting the stops and depth of cuts, duplicate work may be turned out without changing the setting of the machine.

19. Fixtures are provided with devices by means of which they may be clamped to the machine on which they are used. A *milling-machine*, *shaper*, or *planer*, *vise* is a form of fixture. Another form of fixture is illustrated in Fig. 10 (*a*). At *a* is shown the fixture for holding the work *b* while the milling cutters *c* finish both sides of the projection *d* on the work.

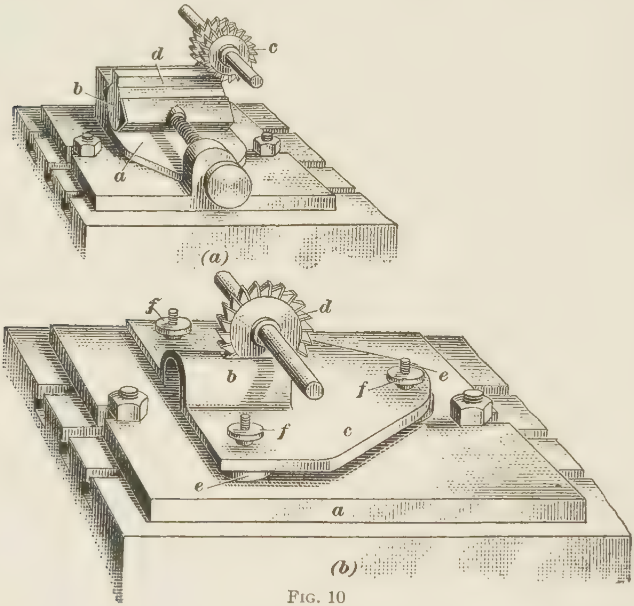


FIG. 10

In Fig. 10 (*b*) is shown a fixture *a* used when milling the slot in the projection *b* of the work *c*. The fixture is bolted to the bed of the machine, and the cutter *d* is shown in position after cutting part way into the work. The work is located on the fixture by the three studs *e*, which pass through the holes previously drilled, the cutting tool having been guided by a jig. The work is held rigidly in position by the nuts *f*. After setting up the cutter, a large number of pieces may be milled without readjusting the setting of the machine.

JIG AND FIXTURE DETAILS

GUIDE BUSHINGS

20. Permanent Bushings.—The guides for the cutting tools, which are usually drills, reamers, or taps, most frequently take the form of hardened steel bushings set into the jig body. The hole in the bushing is made to fit the drill, reamer, or tap shank closely; the outside of the bushing is exactly concentric with the inside.

21. The bushings may be made in various forms to suit different purposes. Common forms of plain bushings, intended to be driven into suitable holes in the jig body, are shown in Figs. 11 and 12. In Fig. 11, the bushing is straight inside and outside, except that the end where the drill enters is rounded out to allow it to enter easily. This plain bushing is the cheapest bushing to make, and, if well fitted to the hole that receives it, is thoroughly satisfactory. The only objectionable feature is that when a drill too large for the hole is forced down on the bushing, it is likely to push the bushing through its seat. This may happen when the jig is used on a multiple-spindle drill press with disastrous results to the drill. To prevent the bushing from being

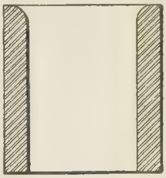
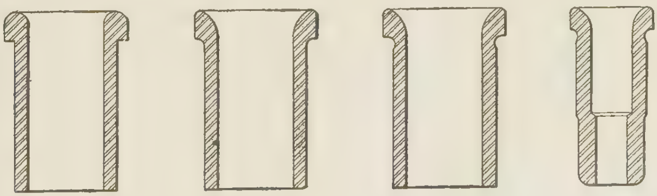


Fig. 11



(a) (b) Fig. 12 (c) (d)

pushed through its seat, it may be allowed to project from the seat. The projecting part is then enlarged to form a shoulder.

22. The most common form of a straight bushing with an enlarged head is shown in Fig. 12 (*a*). The shoulder under

the head is made square. This form is objectionable, however, for two reasons: first, in hardening the bushing, a crack is liable to form in the sharp corner; second, while forcing the bushing home into its seat, the head is rather liable to be broken off. The end that receives the drill is rounded off inside and out, usually semi-circular, as shown.

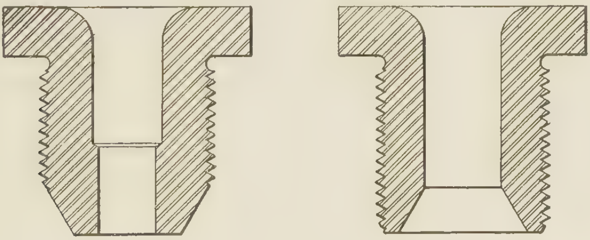
23. A better form of a straight bushing is shown in Fig. 12 (*b*). Here a fillet of liberal size is left under the head, which obviates the liability of cracking in hardening, and reduces the liability of breaking off the head while forcing the bushing home. In the bushing shown, the end is rounded out considerably more on the inside than on the outside; this shape makes it easier for the drill to find the hole and hence is preferable to the semi-circular rounding off shown in (*a*). When the bushing is to be ground on the outside after hardening, it should be very slightly necked down under the shoulder with a round-nosed tool; when grinding the outside, the grinding wheel can then pass clear over the part that is being ground. The necking down is shown in (*c*). On all bushings of this form, the lower outside corners should be slightly rounded, so that they may more easily be put in the seats and the sharp corners of the hardened bushings prevented from cutting the holes in the jigs.

24. The bushing must often project beyond the lower part of its seat, in order that the point of the drill or the end of the reamer may be supported close to the work. In such a case, the bushing may take the form shown in Fig. 12 (*d*). As shown in the illustration, it is counterbored part way down, in order to reduce the friction of the drill against the inner surface of the bushing. The part that serves to guide the cutting tool need generally be no longer than twice its diameter.

25. Clamp Bushings.—A clamp bushing may serve a double purpose; that is, it may be used to guide the cutting tool and at the same time to clamp the work to the jig body. To do this, the threaded part of the bushing is made long enough to allow the end to be screwed down on the work. Frequently, the adoption of one or more clamp bushings will allow a very simple form of jig.

26. In some cases where the work has cylindrical projections or a recess, a clamp bushing may be made to act as a stop for centering the work properly and clamping it at the same time. Thus, if the work has a cylindrical or conical recess, the lower end of the bushing may be turned conical, as shown in Fig. 13 (*a*). If the work is to be centered by a cylindrical or tapering projection, the lower end of the bushing may be recessed conical, as shown in (*b*).

27. Size of Guide Hole.—The size of the hole in the bushing has a very important influence on the accuracy with which the holes are drilled into the work. In all cases, the drill or reamer must fit loose enough in the bushings to prevent binding or seizing. This looseness need not be much; if



(*a*) FIG. 13 (*b*)

the hole is .001 inch larger than the cutting tool, there is little danger of sticking. While the variation between different drills of the same nominal size is not sufficient to be noticeable for ordinary work, this variation becomes quite appreciable when accurate work is to be done by jig drilling.

28. Material for Bushings.—The material to be chosen for the bushings depends on the resistance to wear that is deemed essential. Hardened tool-steel bushings will resist wear better than machinery-steel bushings that have been case-hardened. Machinery steel will answer very well for bushings that are intended for temporary jigs; if the jig is in constant use, however, it is usually advisable to choose tool steel and harden the bushings.

29. Grinding Bushings.—Since the hardening process changes not only the size but also the shape of the bushings, they should be ground on the outside and lapped or ground on the inside after hardening, provided great accuracy in the central location of the guide holes in reference to the seat is deemed essential.

GUIDE STUDS

30. Guides for locating the work on fixtures usually take the form of **studs**. The work to be milled, planed, shaped, bored, or turned usually has holes previously drilled in it and the work must be so located on the fixture that it may be machined true with these holes. The holes must then be accurately located in the fixture and studs made to fit them. One end of each stud is forced into the hole thus made, and the other end fits the hole drilled in the work.

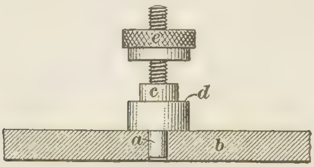


FIG. 14

One form of stud is shown in Fig. 14. Here the end *a* fits the hole in the fixture body *b*; and the hole in the work fits the part *c*, the work resting on the shoulder *d*. The nut *e* is used to clamp the work in position.

CLAMPING DEVICES

31. As has been mentioned, jigs and fixtures are furnished with clamping devices of various forms for the purpose of clamping the work to the jig or the fixture body, or to clamp a part made movable for the purpose of inserting and removing the work.

32. Clamping the Work.—Clamps intended for clamping the work may have various forms to suit different conditions. For some work the *hook bolt* shown in Fig. 15 is very suitable, being cheap in construction and easily applied. The bolt proper passes through a hole in the fixture, which it fits closely. It is made long enough to have the head hook over some projecting part of the work, and may be supplied with a wing nut,

as shown, or have an ordinary hexagonal nut. In some cases, a large nurled nut may be of advantage. The greatest clamping pressure can be obtained with a hexagonal nut and a wrench; a moderate pressure can be obtained with the wing nut or the nurled nut. However, the wing or the nurled nut allows the hook bolt to be applied more rapidly. It will be understood that in order to allow the work to be inserted or removed, the loosened hook bolt is turned so that the head is away from the work; when the work has been inserted, the head is turned toward the work and hooks over it. The clamping is then done by screwing up the nut.

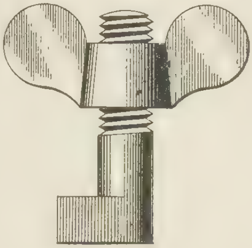


FIG. 15

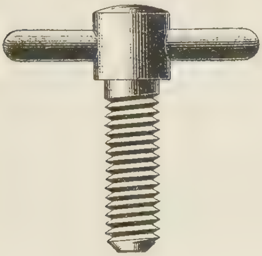


FIG. 16

33. In jigs that partly or entirely surround the work, it is most commonly held in place by setscrews, which may be designed in several ways. When available, drop-forged thumbscrews are generally used, because comparatively little work is required to finish them. When such thumbscrews cannot be obtained, the setscrews may be made as shown in Fig. 16, by driving a cylindrical pin into a hole drilled through the head of the screw. In many cases,

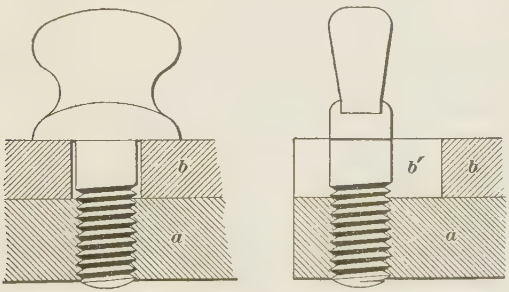


FIG. 17

where only a few parts are to be drilled, the ordinary setscrews that can be bought in the market may be used. These,

however, require a wrench for tightening, and hence are not so readily used as thumbscrews or the screw illustrated in Fig. 16.

34. Clamping Jig and Fixture Parts.—Fig. 17 shows a common clamping arrangement for locking together two parts of a jig or a fixture. The thumbscrew shown is screwed into a tapped hole in the jig body, as *a*. The shank passes through a slot *b′* in the movable part *b* of the jig. This slot is wide and long enough to allow the head to clear it when the screw has been given a quarter-turn from the position shown. Evidently, this is a very rapid clamping arrangement. The only objection is that, as the threads and the bearing surfaces wear, the long way of the head, when tightened, will come in line with the slot in the movable part.

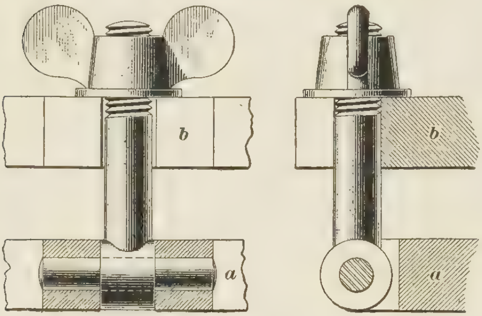


FIG. 18

35. Fig. 18 shows a hinged bolt that is hinged to the stationary part *a* by means of the pin shown. The bolt passes through a slot in the movable part *b*, open on one end, and is provided with a nut and washer. The nut may be a wing nut as shown, or a hexagonal or a nurled nut. Wear of the bearing surface or of the pin joint does not affect the clamping. As the nut must be unscrewed considerably to allow the bolt to be swung clear of the

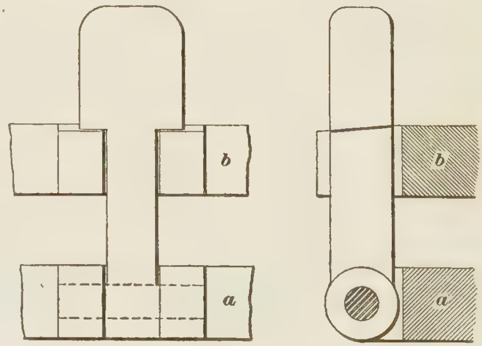


FIG. 19

slot, this arrangement is not quite so rapid as that shown in Fig. 17.

36. Fig. 19 shows a hinged cam-lever pivoted to the stationary part *a*. Its shank passes into a slot in the movable part *b*; the bearing surfaces of the head engage inclined surfaces of the movable part. Where extreme rapidity of clamping is desired, this design can be recommended.

STOP-PINS

37. In order to prevent any shifting of the work in the jig or fixture during the cutting operations, one or more stop-pins may be provided. These pins are usually made cylindrical and are closely fitted to the guide bushing. They should be provided with a suitable handle to facilitate withdrawal. To prevent shifting of the work, a stop-pin is pushed through the bushing into the hole in the work as soon as the hole has been drilled. Since the work must be confined at least in two places to surely prevent it from shifting, two stop-pins are often provided. It is a good idea always to select the holes that are farthest apart for the stop-pins.

JIG AND FIXTURE MAKING

RELIEF OF STRESSES

38. Any part of a jig that is to receive a bushing should be either planed on both sides or left unplaned. Removing the scale relieves the internal stresses in the casting; consequently, if the part is planed on one side only, the piece may be distorted by the stress acting in it. For very accurate work, the body and cover of the jig should be relieved of internal stresses before boring the bushing holes. Should the jig be so shaped that the surfaces cannot be machined, all the holes should be spotted and drilled before boring any of them to the finished size. This precaution is taken because when a few holes are drilled, either in a piece of metal from which the

scale has not been removed or in a piece of unsettled steel, the work will invariably warp. Hence, if each hole was bored after drilling, the distance between the holes would change. This change of distance is more noticeable in the case of holes farther apart.

39. Each hole should be faced when it is bored, to insure the shoulder of the bushing seating properly. Again, after all the holes have been drilled the clamps holding the part to the machine should be loosened sufficiently to allow the work *to go;* that is, to allow the piece to move in the direction in which the internal stresses are acting. These internal stresses are caused by the readjustment which takes place by the partial relief of stresses present in the casting, brought about by removing stock in the drilling operation.

LOCATING HOLES

LOCATING HOLES FROM A DRAWING

40. The problem of correctly locating the holes that receive the guide bushings or studs presents itself usually in one of two ways. Either the holes are to be laid out from a dimensioned drawing or they are to be transferred from a model or templet of the work. The choice of method of procedure depends on the accuracy required and also on other conditions, such as the facilities at hand and the nature of the work.

41. Locating Holes by Scribing Lines.—When extreme accuracy is not required, the centers of the holes are laid out as the machinist lays out his work; that is, by scribing lines with scriber, surface gauge, or height gauge. In that case, all dimensions are transferred from a steel rule. Since the intersections of the scribed lines represent the centers of the holes, they are carefully indicated by a fine prick-punch mark and a witness circle slightly larger than the proposed hole is drawn from each prick-punch mark as a center. There is now the choice of two methods of making the holes. They may be

drilled and reamed in the drill press, or they may be bored in the lathe. Drilling and reaming the holes in the drill press has the advantage of cheapness, but will insure only a fair degree of accuracy in the location of the holes, since any unevenness in the metal, undue pressure on the drill at the start, or dullness will cause the drill to run to one side. With reasonable care in laying out, and in the subsequent drilling and reaming, the holes, as a general rule, may be located within a limit of variation of .005 inch. If the holes are first drilled with a small lead drill, say No. 50, they may be located within .003 inch, which may be considered as the limit of accuracy attainable by this method.

42. The relative accuracy of the method just given is due to the existence of several errors, none of which can be eliminated entirely, although, as the result of accident, they may occasionally be so small as to be insensible. One of these errors is due to an accumulation of errors in the laying-out process. The second error is due to running out of the drill, which is caused either by lack of evenness of the metal or by carelessness, and frequently by a combination of both. A third error is due to the reamer not following the drilled hole. These errors can be minimized by careful work, and the extent to which they can be minimized depends on the skill of the toolmaker.

43. Modification of Scribed-Line Method.—In order to reduce the limit of variation, a modification of the method just given may be employed. This modification will neither reduce nor eliminate the error of laying out, but will greatly reduce the error of making the hole. It will also insure that the axis of the hole is perpendicular to the supporting surface. After laying out the holes, the jig or fixture is strapped against a true-running straight face plate and is trued up successively to the various prick-punch marks by means of a sensitive center indicator. After each truing up, a hole is drilled clear through; the hole is then finished by careful boring with a sharp tool. To do accurate work, the weight of the part that is being bored must be counterbalanced by attaching a suitable

weight to the face plate. The boxes in which the lathe spindle runs must be set quite close and all end movement of the lathe spindle should be taken up. The belt lacing should also be examined; if it shows a decided lump, relace the belt smoothly. Otherwise, every time the lacing strikes the cone of the live spindle, the latter will jump to the extent of the looseness between the spindle and its boxes.

With extremely careful work in laying out, truing up, and boring, the holes may be located within a limit of variation as small as .0015 inch. The method given is limited in its application by the swing of the largest lathe available.

44. Locating Holes by Buttons.—If the holes in the jig are to be located closer than is usually possible by the method just given, contact measurements, as far as practicable, must be substituted for measurements transferred by scribed lines. The tools required are a micrometer caliper of sufficient capacity or a measuring machine, and a number of annular circular steel buttons. These buttons may be of any convenient size; a good size is $\frac{1}{2}$ inch outside diameter, $\frac{1}{4}$ inch inside diameter, and $\frac{1}{4}$ inch thick. They are attached to the work by means of fillister-headed screws of about $\frac{3}{16}$ inch diameter. The buttons should be ground truly circular after hardening and the ends must be square with the cylindrical part.

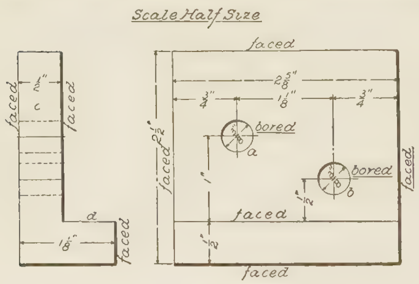


FIG. 20

45. The method of using the buttons for a case where all holes are to be in the same plane is perhaps best shown by an example. Let Fig. 20 be a working drawing of part of a jig in which the holes *a* and *b* are to be located with reference to each other and to the surfaces *c* and *d* within as small a limit of variation as possible. The position of the holes is first laid out by scribing lines with the aid of a surface gauge or scribing block, as *e* in Fig. 21, setting the point of the scriber *f* to a steel

scale resting on the surface plate and held upright by being placed against a square, as shown. For convenience, the scale may be secured to the square by one or two rubber bands. The

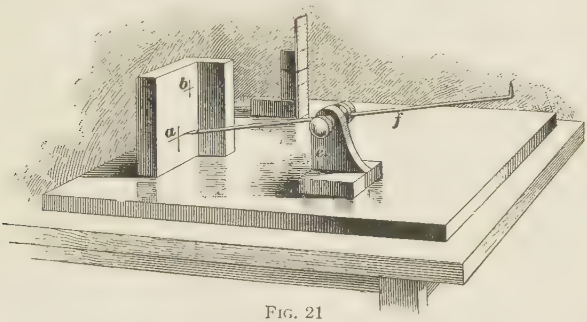
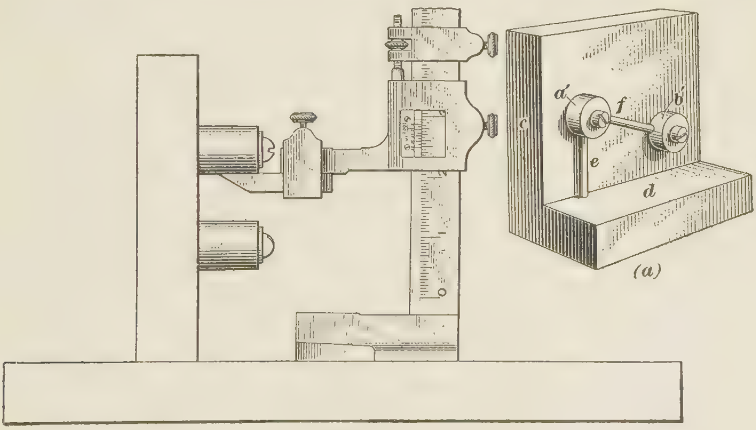


FIG. 21

centers of the holes having been roughly laid out, they are center-punched and then drilled and tapped for the size of machine screw chosen.

46. The buttons, as a' and b' in Fig. 22 (a), are now attached by means of the screws and their correct distance apart obtained



(b)

FIG. 22

by the use of a pin gauge f. Since the hole in the button is larger than the diameter of the screw, it follows that the buttons can

be shifted a limited amount. Let it be assumed that the buttons are both .5 inch diameter. Then, to place the button a' at a distance of 1 inch, as in Fig. 20, from d, a pin gauge, as e, Fig. 22 (a), is made equal in length to the difference between the radius of a' and the given dimension, or $1-\frac{.5}{2}=1-.25$ $=.75$ inch long. Then the button is shifted until the gauge e, when perpendicular to d, will just touch d and a' with the same degree of tightness with which it fits the micrometer. The same result may be obtained by setting a vernier height gauge to the proper height and adjusting the button to it as shown in Fig. 22 (b).

To locate the axis of a', Fig. 22 (a), in reference to the edge c, the jig may be placed on a surface plate with the surface c resting on the plate. Then, in a manner similar to that employed to locate the button in reference to d, it may be located at the proper distance from c. The screw may now be tightened and the proper adjustment of the button tested again, since the tightening process is liable to shift it.

47. The location of b', Fig. 22 (a), in respect to d is simply a repetition of the method employed to locate a'. When locating it in reference to the button a', two ways may be employed. If the center-to-center distance between a' and b' is known, subtract the sum of the radii of the two buttons from it and cut a piece of steel, as f, to it, and use this piece to locate b'; or, the button b' may be located from the surface c in the same manner that a' was located in reference to that surface. After locating b', it is clamped tightly to the piece and then tested again. If found correct, the piece may now be strapped to the face plate of a lathe and trued up by shifting until one of the buttons runs true; that is, until its axis coincides with the axis of the lathe spindle. An indicator is indispensable for this process.

It may be well to call attention to the fact that, in order to do any accurate work, the lathe spindle must be truly cylindrical and must fit the boxes very closely. The face plate should also be counterbalanced and the belt lacing properly

fixed. After truing up, the button may be removed and the hole bored to the required size. The other hole is similarly treated.

48. Another accurate way in which to locate the holes in the jig is shown in Fig. 23, in which another form of button is used. The parts *a*, *b*, and *c* of the buttons are turned concentric from a rolled piece of stock and of such diameters that when the parts *a* are in contact with *d* the centers of the buttons will be at the desired distance from *d*, and when the parts *b* touch each other the buttons will be at the desired center-to-center distance apart. After the buttons are set, they are clamped to the jig by the screws *e* and adjusted on the lathe face plate until the parts *c*, in turn, indicate true. When the work is set so that either one of the parts *c* indicates true, the button is removed and the hole for that bushing is drilled and bored. Parts of buttons must sometimes be cut away for clearance, as shown in the illustration.

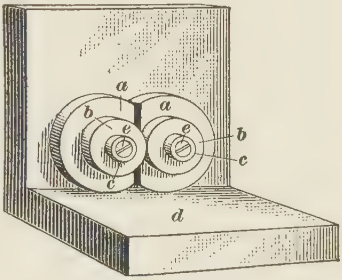


FIG. 23

49. In Fig. 24 (*a*) is shown a working drawing of a jig part. As will be observed, the distance between the centers of the holes *a* and *b* is not given. These holes are, however, definitely located by the dimensions given on the drawing; that is, by horizontal and vertical distances. This illustrates the manner in which the draftsman may give the necessary information to the toolmaker. The toolmaker must then figure the distance between the holes, as he must have this information in order to lay out the work or set the buttons.

A dimension of this nature may be found in the following manner: The triangle *c d e* is completed by drawing the line *d e*. The distance *d e* between the centers of buttons is then found by squaring the other two sides, adding the squares and finding the square root of their sum.

In the case illustrated, the length of the side *c d* is .42 inch, and that of the side *c e* is .72 inch. The squares of these sides

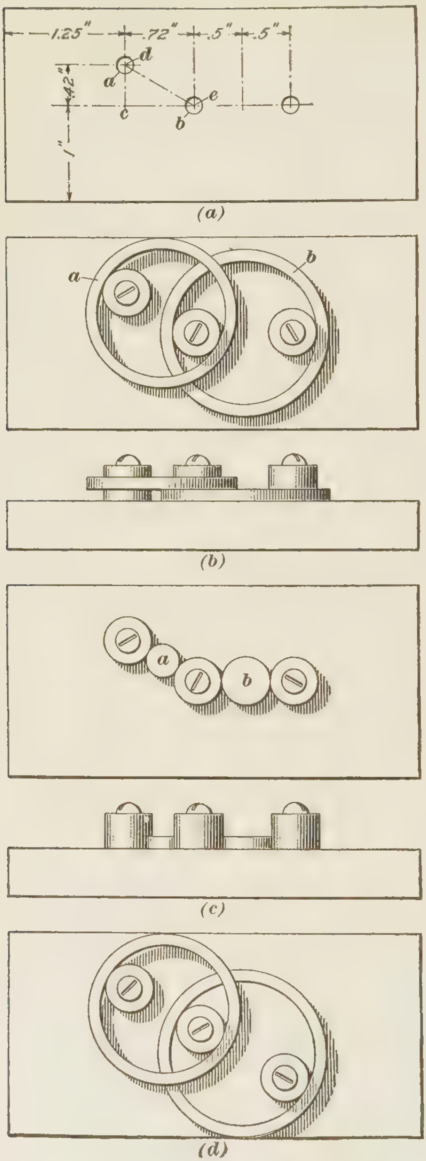


Fig. 24

are .1764 and .5184, respectively. The sum of these squares is $.1764 + .5184 = .6948$, and the square root of this sum $= \sqrt{.6948} = .833$ inch.

50. Fig. 24 (*b*) and (*c*) illustrate a method of locating the buttons by means of rings and disks. Its advantage lies in the fact that to turn a piece or bore a hole to a certain diameter is much easier than to cut a rod a given length. The distance between the centers of the buttons in the drawing shown in (*a*), is found to be .833 inch; and, using buttons having an outside diameter of $\frac{1}{2}$ inch, the distance between the outsides of the buttons is $.833 + .5 = 1.333$ inches.

The buttons may be located with the correct distance between centers by the use of rings *a* and *b* Fig. 24 (*b*); ring *a* is bored to a diameter of 1.333 inches, and ring *b* to 1.5 inches; the buttons are adjusted until the rings just slip over them. Disks, as *a*, *b*, Fig. 24 (*c*), may be used instead of the rings.

On referring to Fig. 24 (*d*), it is obvious that whereas the rings or disks will indicate whether the distance between the centers of the bushing holes is correct, yet they will not show whether their location is according to the drawing.

51. The buttons are adjusted on the jig part until they are shown to be properly located by measuring with a micrometer caliper, as shown in Fig. 25 (*a*); by a micrometer or vernier depth gauge, as in (*b*); by a height gauge, as in (*c*), or by an adjustable size block, as in (*d*). If measured with a micrometer caliper, as in (*a*), a parallel strip *a* is held against the edge of the work by a toolmaker's clamp *b*; then, the measurement indicated on the caliper will equal the distance of the center of the button from the edge of the jig part plus the thickness of the parallel strip, plus half the diameter of the button. If measured with a height gauge or an adjustable size block, as in (*c*) and (*d*), the work and instruments are supported on a surface plate to which it is essential that the axis of the button be parallel. The size block is set to a micrometer.

By the use of the test indicator, with the rings or disks, Fig. 25 (*e*), the buttons may be very accurately located. An auxiliary disk *a*, view (*f*), having a diameter equal to the distance of the center of the bushing hole from the edge of the jig part plus half the diameter of the button, in this case 1.67 inch, is first made to be used as a standard in setting the indicator. This disk, together with the surface gauge *b*, is supported on a surface plate *c*, when setting the indicator *d*. When measuring the height of the buttons, the edge of the jig part, which must be parallel to a line passing through the centers of the button, and the surface gauge rest on a surface plate.

52. Should all the holes lie in a straight line, the test indicator adapts itself readily to measuring the height of the buttons, as shown in Fig. 26 (*a*). In this case all the buttons must be of the same diameter. As before, both the surface gauge and the jig part must be supported on a surface plate, and the distance between centers is maintained by use of the rings or disks.

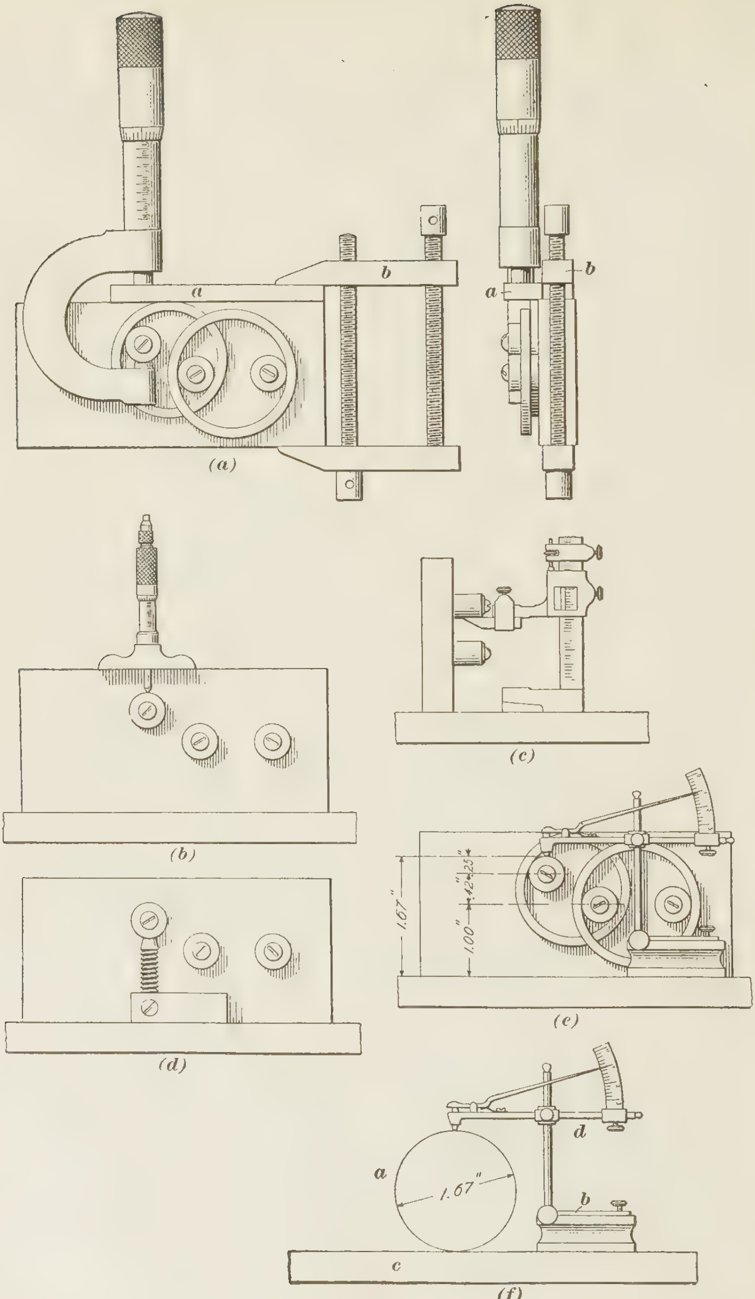


FIG. 25

Sometimes a parallel strip as *a*, view (*b*), is used to aline the buttons; but this method is not to be depended on for close work, as one or more of the buttons may lack one or two thousandths of an inch of touching the strip and pass unnoticed. A thousandth of an inch is very difficult to see except under ideal conditions.

53. A sensitive test indicator should be used when possible, as some of the errors due to a varying sense of feeling will be eliminated. The disks employed to set the indicator depend for their accuracy on contact measurements made by micrometer calipers. The sense of touch is, however, owing to constant use, developed to a high degree in the use of micrometers. Let it be assumed that a very slight error is made in measuring the disk diameters; it would then follow that this same error, neither magnified nor diminished, would be transferred to the jig, using the test indicator, because the sense of feeling does not affect the reading shown by the pointer of the indicator. Great care must be taken in making the disks and a delicate sense of touch must be developed to measure very accurately with micrometers.

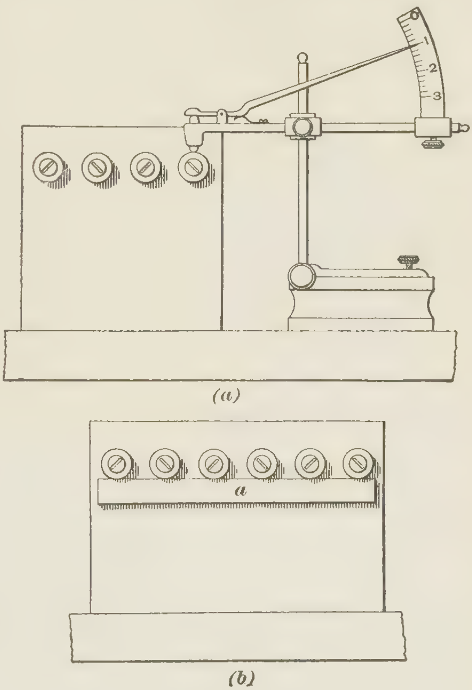


Fig. 26

54. Setting the jig buttons is a slow operation. They may measure exactly the right distance in a horizontal line, but not

in a vertical line. The screws must then be loosened a little and the buttons shifted by light tapping. After adjusting the buttons till they are the right distance apart in a vertical line, they will probably be found to vary when measured in a horizontal line. This shifting must be continued until the buttons are found to be the correct distance apart in both directions.

If the work must be done with extreme accuracy, and especially if the work is an expensive piece, or if there is danger of accidentally displacing one or more of the buttons a little while strapping the work to the lathe face plate, it is best to set but one button at a time. After setting the button, the work is clamped to the face plate of the lathe and the button indicated true and removed. The work is then spotted deeply with a keen-cutting spotting drill, drilled, and bored to size. A reamer is not suitable for finishing a hole where accuracy between centers is required. At this setting a light chip is also taken off the face of the work surrounding the hole, to insure that the bushing head will seat properly. After removing the work from the lathe, a pin is turned to a wringing-fit of the hole. This pin replaces the button previously used for this hole in locating the next button.

55. Locating Holes by Milling Machine.—A milling machine may be used to locate the bushing or stud holes. The dial on each handle of the machine is graduated so that the .001-inch divisions are about $\frac{1}{16}$ inch from each other. When the machine is new, very accurate results can be obtained by the use of these graduations; but after the threads on the screws become worn, they cannot be relied on for accurate work. In such an event, a vernier scale is attached to the movable table and a true scale to the stationary part of the miller. Quite accurate work may be done by this method. After the work has been set up on the milling machine so that the first hole, which has been previously cut, lines up with the spindle, the vernier is set to some arbitrary number and all future measurements are figured from it.

56. The work cannot be set up on the milling machine by the use of dials or the vernier so that this first hole will line

up with the spindle and be the exact distance required from the edge of the jig. In Fig. 27 are shown two methods of setting up the work. In (*a*), the jig *a* has been fastened to the angle iron *b*, which is clamped to the table *c* of the miller; the button *d* has been accurately located on the jig by one of the methods already described; the piece *e*, which is held in the chuck *f* attached to the spindle of the milling machine, is turned in position to the same diameter as the button *d*, the cutting tool being held in the milling-machine vise; and the sleeve *g* is bored or reamed, in the bench lathe, so that it is a sliding

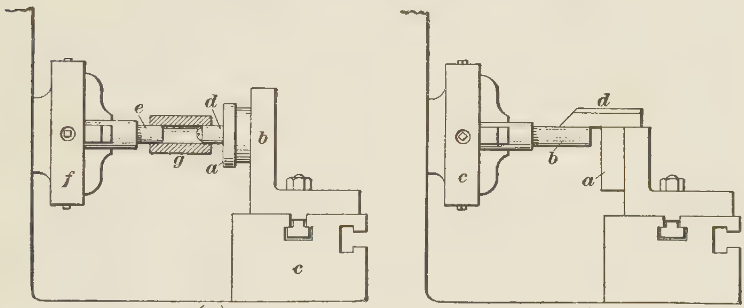


FIG. 27

fit on the piece *e* and the button *d*. The milling-machine knee and table are now adjusted so that the sleeve will slide without springing over the button.

In Fig. 27 (*b*), the jig *a* is fastened to the angle iron as before; and the piece *b* is turned in the chuck *c* by a tool held in the milling-machine vise to a diameter of, say, 1 inch. The knee of the miller is now adjusted until the top of the piece *b* is brought flush with the top edge of the jig; a knife straightedge *d* is used to test the alinement. The center of the milling-machine spindle is now known to be $\frac{1}{2}$ inch below the top edge of the jig, which distance gives the needed starting point from which to work.

LOCATING HOLES FROM TEMPLETS

57. Guide Bushings or Studs in Different Planes. When the guide bushings or studs do not lie in the same horizontal plane, as, for instance, when a jig having the cross-section

shown in Fig. 28 is to receive guide bushings in the places indicated by the dotted lines at *a* and *b*, no dependable contact measurement between the buttons can be made if they are attached to the top and flange of the jig. In such a case, a temporary flat plate, as *c*, may be attached and the buttons may be fastened to this plate in order to bring them all into the

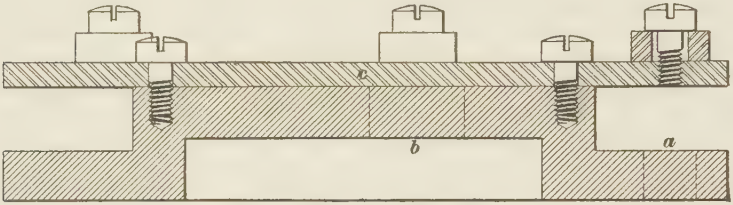


FIG. 28

same plane. This plate must be straight and parallel, and so fastened as to avoid any possibility of shifting. The holes are bored through the plate *c* and the jig as if they composed a solid part. If several duplicate jigs must be made, the plate *c* may be used for all of them. When the first one is finished the remaining jigs may be trued up by the holes in the plate, using an indicator for the purpose of obtaining accuracy. The plate is not needed when the holes are laid out on the miller.

58. Making Duplicate Parts of Jigs.—Often a few pieces of a jig are alike and a templet is used to facilitate making these parts. This templet is usually made of a metal plate or a thin casting; it is carefully laid out and the holes are bored to size. Dowel-pins are employed to hold the templet to the work and the holes are transferred from the templet in various ways, depending on the degree of accuracy required.

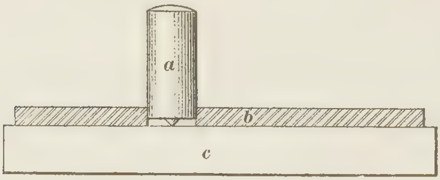


FIG. 29

A short spotting drill, whose collar fits the hole in the templet, may be used; or, a center punch, as shown at *a*, Fig. 29, may be employed to locate the centers of the hole. The outside

diameter of the center punch is made equal to the bore of the hole in the templet *b*. After locating the centers in the work *c*, the templet is removed and the work strapped to the lathe face plate, and each hole in turn is indicated true, drilled, and bored to size.

Should both sides of the parts be flat, the pieces may all be clamped together, laid out, drilled, and bored together.

59. Locating Holes in Straight Line.—Should the jig part have a number of holes of equal size in a straight line, a templet of the form shown in Fig. 30 may be used to locate them very accurately. A flat plate *a* is clamped or doweled to the jig part and three holes are carefully laid out with buttons or other methods and bored to size. The piece is then removed and three pins are turned to a wringing fit in the holes and inserted as shown in the illustration; these pins are, of course, of the same diameter as the holes in the jig. The pins *b*, which act as dowels, are inserted in the last two holes bored in the jig part, the templet is fastened to the work, and the work is clamped to the lathe face plate when the pin *c* indicates true. The templet is now removed, and the hole in the jig is drilled and bored to size. This operation is repeated until all the holes are bored. With this method, should a variation in center distances occur, it would be detected when an effort was made to put the pins in the holes already bored.

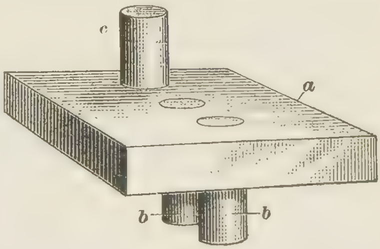


FIG. 30

60. Locating Holes From a Model.—Sometimes a model is supplied and a drilling jig must be made to drill the holes the same distance apart and the same size as are the holes in the model. If the nature of the model will permit, it can be clamped to the jig part and used as a templet for locating the holes.

61. Accuracy in Locating Holes.—It should be kept in mind that the degree of accuracy obtained with the methods

just described depends entirely on the toolmaker. There are many chances for errors to creep in due to undue pressure on the buttons when measuring with micrometers, buttons not being exactly the size figured, the hole in the bushings being slightly eccentric, etc. The greatest care should be taken to reduce these errors to a minimum.

MAKING BUSHINGS

62. Whether the bushing is made of tool steel and hardened, or of machinery steel and case-hardened, the hole in the bushing should be concentric with the outside. A uniform thickness of wall is thus provided, so that the expansion and contraction of the steel during the hardening process will be as equally distributed as possible. Unequal expansion or contraction will distort the hole so that it must be ground true.

63. Turning, Boring, Hardening, and Grinding Inside.—A piece of round stock *a*, Fig. 31 (*a*), from which the bushing is to be made is chucked approximately true in the lathe and turned to within .015 inch of the finished size; it is then drilled, bored or reamed nearly to the finished size, chamfered, and necked as shown. After polishing the end, the bushing *b* is cut off and hardened. The bushing is next warmed up a little, to relieve the internal stresses set up in the hardening operation, and the scale on the outside is removed to further relieve these stresses. If the size of the hole will permit the use of an internal grinding machine, the hole is now ground to size. The bushing must be held when grinding by some method that will not distort the work. One way of doing this is to bore out a piece of stock, as *a*, Fig. 31 (*b*), to a wringing fit on the bushing *b*. The bushing is then wrung into this piece and the hole is ground. After removing the bushing from this device it will be found that it has not sprung out of shape, as it would have done if it were held in an ordinary universal or independent chuck, owing to the pressure of the jaws.

64. Lapping Holes in Bushings.—Very accurate bushings, or those having a hole too small to permit of grinding

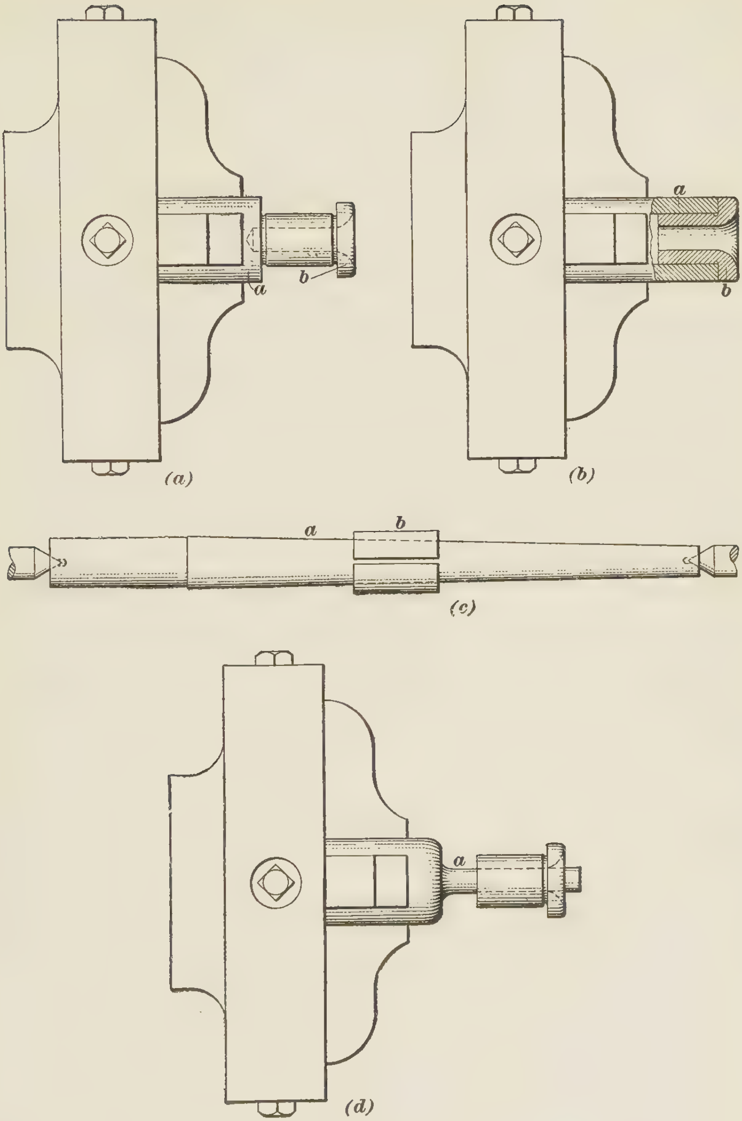


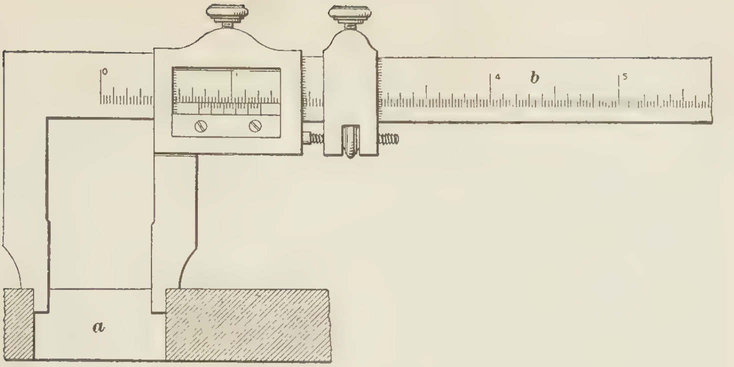
FIG. 31

with the available equipment, are finished by lapping. It is essential that the lap fit the hole at all times during the operation. As the abrasive used will soon reduce the diameter of the lap, means to compensate for this rapid wear must be provided.

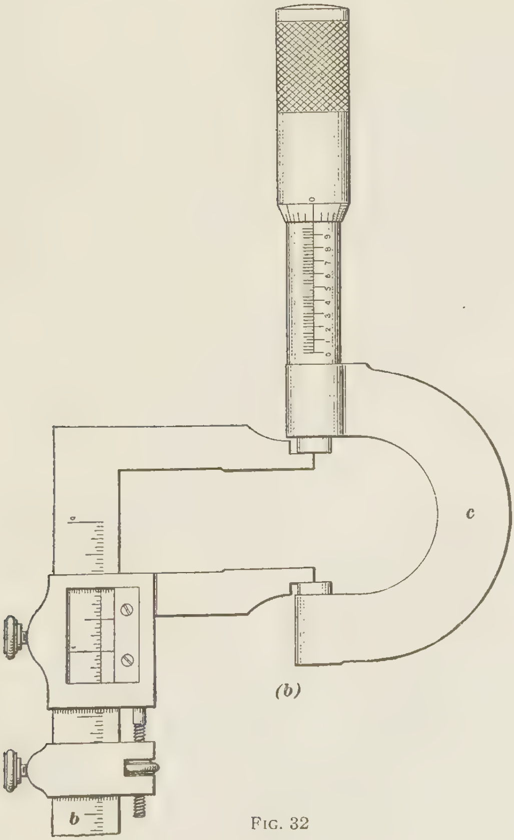
One way of doing this is to use a taper lap arbor of steel *a*, Fig. 31 (*c*), and a shell lap *b* of lead, copper, brass, or cast iron, taper reamed to fit the arbor. In making the lap, it is turned to within a few thousandths of an inch of the finished size and then slotted, after which it is forced on the arbor until it is spread just enough to fit snugly the hole to be lapped. The lapping abrasive, which usually consists of flour emery and oil mixed to a consistency of thin paste, is applied to the lap and the bushing hole; and the lap arbor is run at as high a speed as is practicable. When lapping, the bushing is moved back and forth over the lap, and when the lap becomes worn it is forced farther along on the taper arbor. After the lap has become thoroughly charged with the abrasive, all that is needed is to keep it moist. Surplus abrasive would merely ride between the lap and the bushing. A lap of this kind is a miniature emery wheel and the best results are obtained when the abrasive is evenly embedded in the lap and kept moistened with kerosene, or other thin oil.

65. Grinding Outside of Bushings.—A rod *a*, Fig. 31 (*d*), is now ground in the chuck to a wringing fit in the bushing, care being taken not to make the fit too snug, as any tapping or undue pressure in forcing the bushing on the rod would probably cause the rod to run out of true. As each hole in the jig is bored, there is apt to be a variation of one or two thousandths of an inch in their sizes; consequently, each bushing is ground to a force fit for the hole it is to occupy.

66. Measuring Diameters of Holes.—In Fig. 32 is shown a good way to measure the diameter of the holes *a*. The measurement is transferred with a caliper square or a vernier caliper *b*, as shown in (*a*), and the distance across the jaws of this instrument is measured by a vernier micrometer *c*, as illustrated in (*b*). When transferring the measurement,



(a)



(b)

FIG. 32

a delicate touch should be employed, as the long jaws of the instrument will spring considerably. With a vernier caliper, any measurement closer than .001 inch is a guess; whereas, with a vernier micrometer, .0001-inch. measurements may be readily obtained when the toolmaker becomes skilled in the use of micrometers.

67. Forced Fit of Bushings.—For a force fit, the following allowances are ample: For bushings $\frac{1}{4}$ inch in diameter, .0005 inch; for bushings from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, .001 inch; and for bushings greater than $\frac{1}{2}$ inch in diameter, from .001 to .002 inch. Should too great an amount be allowed, the pressure required to force the bushing home will close the hole somewhat. The bushings should be forced in with a steady pressure, rather than be driven in. After all the bushings are in the jig, the center-to-center distances between them are tested by inserting turned pins in the holes and measuring from pin to pin. This is done to check the accuracy, or, in other words, to detect a possible error due to a mistake in laying out the holes.

DIES AND DIE MAKING
(PART 1)

DIES

1. Dies are devices for cutting, forming, or otherwise working metals and other substances. They are ordinarily grouped in pairs and act together, being moved toward one another, usually under heavy pressure. One die alone could not do the work; its mate must press the material into it. Where one die is smaller than and enters the other, the entering part is called the **punch,** and the part into which the punch enters is called the **die** and sometimes the *matrix*. When either part performs a special function a special name may be given to it.

2. The punch may be attached to a part called the punch plate, and the punch plate is fastened to a part called the punch holder. The general types of these parts are shown in Fig. 1. The punch plate *a* contains the punch or punches *b* and is secured to the punch holder *c*. The dowel-pins *d* fit in the dowel holes *e* and locate the plate on the holder. The plate is held in position by screws by means of the countersunk holes *f* and the tapped holes *g*. The shank of the holder may be made either round or square.

In Fig. 2 is shown a punch *a* and punch plate *b*; they illustrate the types used where there is a severe pull on the punch as in drawing dies. The punch plate is bolted to the ram *c*. A die and its shoe are shown in Fig. 3. The **die shoe** *a* is usually bolted to the bed *b*, Fig. 4. The die *b*, Fig. 3, is located in its shoe by the dowel-pins *c* and clamped in position by the screws *d*.

3. Various forms of attachments are used on dies, chiefly on cutting dies. **Gauges** are used to locate the work and **strippers** to remove the stock from the punch.

4. A punch press, two forms of which are illustrated in Figs. 4 and 5, is a machine by which are operated dies that cut and shape metal or other substances. The presses shown are

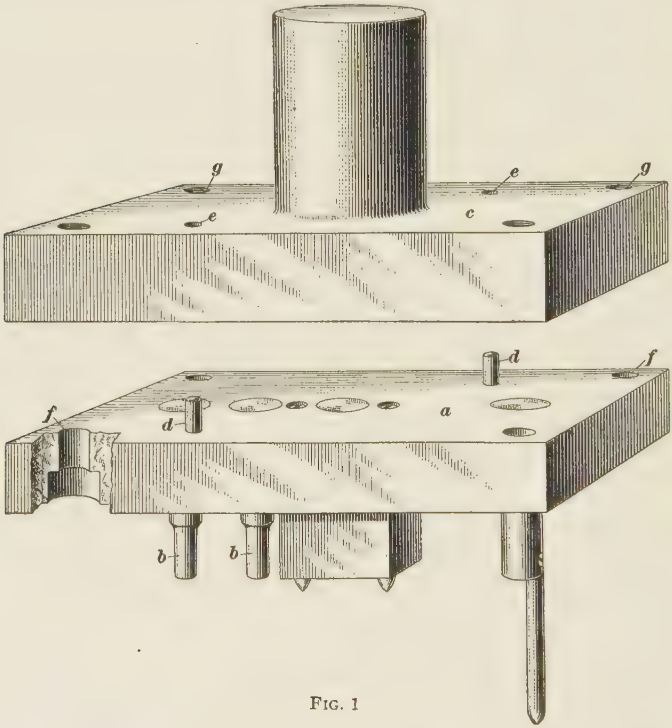


FIG. 1

driven by belts on pulleys *a*. By pressing down the treadle *d* the clutch *e* is thrown into action and the ram *f* is driven down and up by the crank or eccentric *g*. Adjusting nuts *h* permit adjustment of the height of the ram to suit the work. Another style of press is shown in Fig. 6. This press is driven by a belt on tight and loose pulleys *a*, the eccentric receiving its motion through the intermediate gear *j*. The pulley *i* is a balance wheel. Sometimes a press is provided with two rams,

one working within the other. Presses with a single ram are called **single-acting presses**; those with two rams, one working within the other, are called **double-acting presses**. The inner ram is called the **plunger.** Presses provided with three rams are called **triple-acting presses,** two rams being in the head of the press, as in double-acting presses, and one ram or plunger operating in the lower part of the die through the bed or bolster plate.

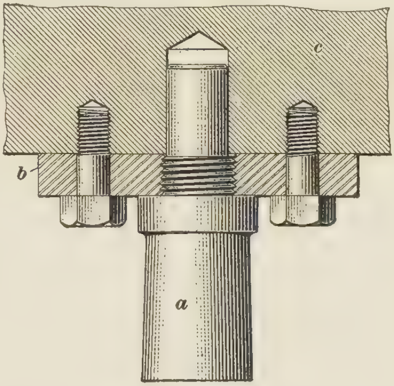


Fig. 2

5. The punch holder *c*, Fig. 1, is fastened to the ram *f*, Fig. 4, by means of bolts in the clamp *c*. A **bolster plate** *b*, Fig. 6, is a flat plate usually having a hole in the center, which serves as a subbase for the punch press. A bolster plate may be clamped in any desired position. When using a small die in a press, the employment of a bolster is often necessary because the holes in the press beds are larger than the die. The bolster plate also assists, in small work, in getting the right distance between the punch and the die.

A supplementary press, called a **subpress,** consists of a base *a*, Fig. 7, which is clamped to the bed or bolster plate, a frame *b* fitted to the base, and a plunger that slides vertically in the frame. The plunger head is connected to the ram of the main press by a button *c*.

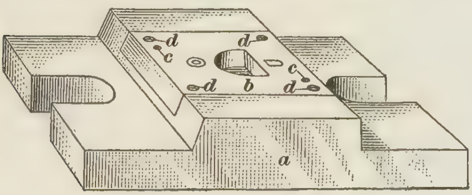


Fig. 3

6. Classification of Dies.—Dies may be classified as *cutting dies*, *shaping dies*, and *combination dies*. Each of these classes may be subdivided into a number of divisions.

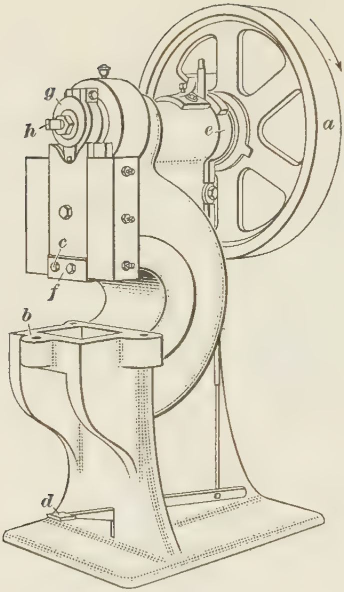


Fig. 4

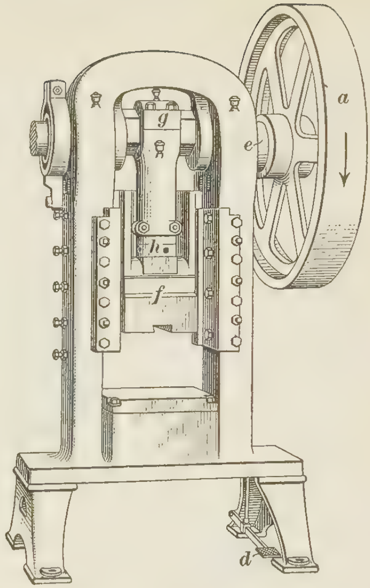


Fig. 5

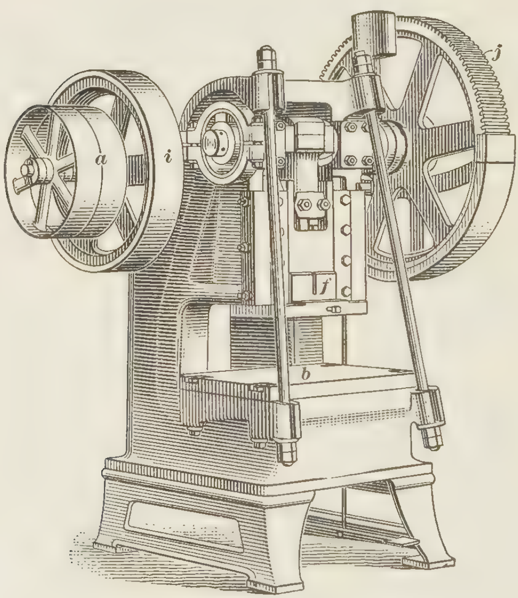


Fig. 6

Cutting dies are those which cut or punch out required pieces of work.

Shaping dies are those which change the form of the stock from its original condition, without cutting or punching out any of the stock.

Combination dies are those which combine the operations of cutting and shaping.

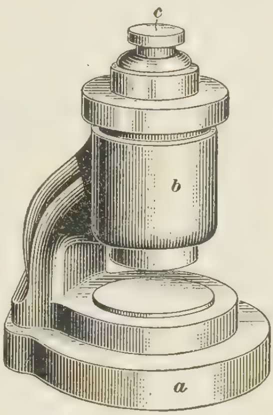


FIG. 7

7. Forms of Dies.—Some of the common forms of dies are shown in Fig. 8. In (*a*) is shown a shearing punch and die well adapted to cut off bar metal or make short, straight cuts; in (*b*) is shown a die used to blank and form cups. This type of die will be considered fully in the discussion of combination dies. A square die used to make sardine cans is shown in (*c*).

8. Dies may be of the *single-action*, *double-action*, or *triple-action* types. A **single-action die** is one in which, during the operation, neither the upper nor the lower part has any motion within itself, the movement of the stripper plates excepted.

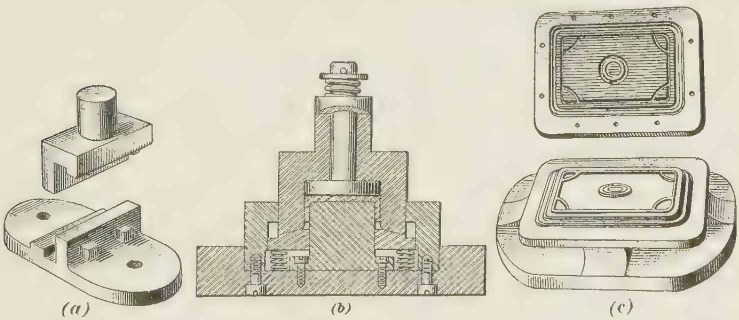


FIG. 8

A **double-action die** is one in which, during the operation, a punch or die moves within either the upper or lower part of

the die, the secondary movement being obtained either by springs or a double-action press.

A **triple-action die** is one in which two punches or dies, or one punch and one die, move within the upper and lower parts

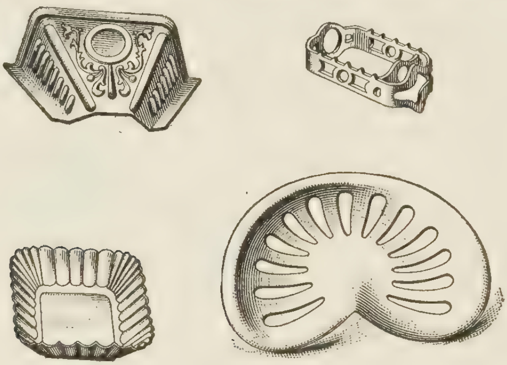


Fig. 9

of the die, the secondary movements being obtained either by springs, a triple-action press, or springs and a double-action press.

9. Articles Made by Dies.—The range of useful articles made by dies is very great, it being possible to make articles of almost any shape that are accurate enough for a great variety of work. Articles can also be made by the use of dies at a lower cost than would be possible by any other method. Examples of a few of the many shapes produced by dies are shown in Fig. 9.

DIE MAKING

HEAT TREATMENT AND FIT OF DIES

HEAT TREATMENT

10. Materials Used in Dies.—Cutting dies for thick and hard metals must be made of the best quality of steel, hardened to the greatest degree it will stand without crumbling. Punches for piercing soft metals, say, under $\frac{1}{32}$ inch thick, may be left moderately soft. When the edges of a soft punch, used on brass, lead, copper, paper, etc., become dull, the punch may be hammered on its end when cold and upset to bring the cutting edge to place again. The face of its hardened mate is then sharpened by grinding, after which the die is forced over the punch, thus shaving the punch to a perfect fit. In various forming dies, especially where the work has no vertical edges, the working parts may be of untempered steel, usually of high carbon, to secure greater hardness and durability. In other cases the working surface of forming dies, and especially of drawing dies, are made of good quality cast iron, especially when the cuplike shapes, such as household utensils, to be formed or drawn are of an approximately spherical or conical form, the exact diameter not being essential. In other cases, wrought iron or mild steel, sometimes case hardened, is good enough for working surfaces. There is danger in heating any part of a die after it is once brought to shape, either for hardening or case hardening. In every hardening operation there is danger of cracking and distorting the metal.

11. Uneven Heating of Dies.—A very uniform heat is one of the most essential points in the successful hardening of steel. To better illustrate the effect of uneven heating, assume

that the die is placed in an open charcoal forge. A blast is necessary in an open fire. The pieces of charcoal interrupt the blast, causing it to strike the die at various points, possibly two or three forced flames, as indicated at *a*, Fig. 10, centering on one spot of the die. The result is that the portions of the die receiving these hot blasts will expand faster than the portions not directly in contact with the blasts.

Fig. 10

12. Cause of Cracks.—Suppose that the die *f*, Fig. 11, is to be hardened and that it is placed in the forge, Fig. 10, so that a direct blast *a* may come in contact with the part *b*, Fig. 11, of the die. The parts *b* and *c* will then be heated quicker than the rest of the die. This is called **local heating.** The parts *b* and *c* are likely to become overheated and the steel injured. They will also expand more rapidly than the heavier parts, which heat more slowly, and if the construction should be such that the lighter parts are not free to expand, stresses will be caused in the die that may crack or warp it. Even when the lighter parts are free to expand local stresses may appear at the points where the lighter parts join the heavier, as at *d* and *e*, causing weak spots. The thin walls around the holes *g* are also likely to be affected.

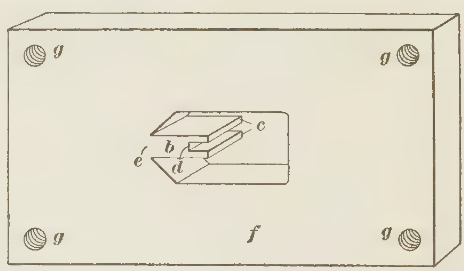


Fig. 11

13. Even when the die has been uniformly heated to the desired temperature and dipped in the quenching fluid, the

hardness will depend on the rapidity with which the heat leaves the work. The water will penetrate the holes *g*, conducting the heat from the wall about the hole, and it will surround the projecting parts *b* and *c*, chilling them much faster than the main body of the die. The contraction of the metal as it chills is the most common cause of cracks. When the parts *b* and *c* chill, they contract sooner than the main body of the die. When the main body contracts, internal stresses tending to cause further weakening will be set up at points *d* and *e*, which have been previously weakened by uneven heating. As the main body continues to contract it acts against the part *b*, which has already chilled and contracted, and cracks at *e* will almost invariably result.

14. Prevention of Cracks.—In order to guard against cracks, the openings, including screw holes, may be plugged with asbestos meal or the screw holes may be plugged with loose-fitting screws. Fireclay is sometimes used; but the results are not satisfactory as the heat causes the clay to shrink by driving out the water contained in it. The clay will then either fall out or leave openings allowing circulation of water, which carries the heat away from certain points faster than others, thereby causing unequal contraction.

15. Heating for Hardening.—The toolmaker must know the heat required to harden the steel. A bright cherry-red heat will give good results for nearly all carbon tool steel, whereas a sizzling white heat is required for the high-speed steels. If the steel used is unknown to the toolmaker, he may cut off a few pieces, heat them to different degrees, and quench. By comparing results, the heat required can usually be selected.

16. Prevention of Local Heating.—A muffle furnace should be used when possible, as the direct force of the blast does not come in contact with the die, as in the open forge. During the heating, the die should be frequently moved about, whether a muffle furnace or an open fire is used. The direct contact of the blast against the die, in using an open fire, can be prevented by placing the die on a piece of sheet iron laid on the forge and covering it with small pieces of charcoal. The

location of the die is frequently changed by shifting the iron plate. After the die has reached the proper temperature it should be dipped. Allowing the die to soak in the fire after the proper heat is reached causes an oxide to form on the die surface and hence softens the surface by burning or decarbonization; that is, the carbon is burned out of the surfaces.

17. Dipping.—After the die has been uniformly heated it is gripped with tongs and plunged in the quenching fluid. If water is used, one hand may be placed in the bath and the die touched lightly from time to time. The instant the die becomes cool enough to permit almost constant contact of the fingers, remove it from the bath and allow the heat from the forge to flash over the surface for an instant. Even contraction will thus be assisted by keeping the die heated uniformly while the heat from the inside is flowing to the cooler portions. Should the die be placed on a cold anvil directly after its removal from the hardening bath, the heat in the die would be conducted away at the point of contact with the anvil and cracks would probably result.

18. Many toolmakers become expert in hardening by allowing the die to remain in the bath until the vibration ceases on the tongs. Other toolmakers leave the die in a bath of water or brine until the outer surface has become hardened and then plunge the die quickly in an oil bath, letting it cool in the oil. A great objection to this method is that the heat in the center of the die, on its removal from the water or brine, will rush to the outer surface and soften the die during its transfer to the oil.

19. The hardness of a die depends on its temperature when dipped and the rapidity with which the heat leaves the die while in the bath. If clear water is to be used, the die should not be heated to as high a temperature as when oil is to be used.

Oil does not carry off heat so rapidly as water and will greatly reduce the chances of cracks.

20. Drawing Temper of Dies.—After removal from the bath, the die should be laid on ashes or other material that holds

the heat and the cutting surface brightened with emery cloth, so that the color may be recognized. The temper may be drawn and good results obtained by placing the die on a bed of hot coals, no blast being used, and dipping it in water when the desired color appears. A more uniform temper will be obtained by heating a heavy plate to a dark-red color and placing the die on the plate with its face up, by which process the temper is drawn. The best way to temper dies, if equipment is available, is to immerse the die in a hot oil bath that is maintained at a temperature of from 450° to 500° F. After the die is heated to the temperature of the bath it is removed and allowed to cool in the open or it may be cooled in water. The die is, of course, hardened before it is tempered.

21. All dies should be rather hard, regardless of the material on which they are used, since the punch is fitted by being forced into the die. For most materials cut with dies, carbon-steel dies will prove satisfactory if drawn to a dark straw color. If harder materials are to be punched, the die should be left harder, say very light straw, and in some instances, as when springs are cut out of tempered strips, the die should be warmed only enough to relieve the internal stresses. In any case, the die should be dipped in oil when the desired color appears, to prevent drawing the temper further.

22. Modern Way of Hardening and Tempering.—In modern factories hardening and tempering is done with the aid of pyrometers. This is the most satisfactory way. The temperatures best adapted for hardening and tempering have been ascertained by experience. When hardening rooms are fitted up with muffle furnaces, pyrometers, oil tempering baths, etc., an expert hardener is usually employed. Hardening in the past has been largely guesswork, much depending on the illumination of the room. When sunbeams are near the forge the temperature of the work cannot be determined by the color even by the experienced eye. On a dark day or in a dark room the color will appear redder than it would on a bright day or in a bright room. The temperature may, however, be determined very closely with a pyrometer. One of the tool

steels for best results, must be heated, when hardening, to a temperature between 1,400° and 1,450° F. This allows a range of only 50°, which makes accurate methods necessary in determining temperatures.

23. Hardening the Punch.—The punch should neither be entirely submerged in the bath nor placed in the bath a certain distance and held there; but should be moved up and down as far as the shoulder, always leaving $\frac{3}{4}$ inch of the punch submerged. There will be heat enough in the shoulder and shank to draw the temper of the punch, and the heat will rush into the hardened part and make the contraction more even where the soft and hard portions join. If placed in the bath a certain distance and held there, the punch is liable to crack or bulge at the water-line.

FIT OF DIES

24. Degree of Accuracy Required in Dies.—In deciding the material, hardness, and general quality of a punch and die, the material to be worked and the amount of probable production must be ascertained. If but a small number of articles are to be made, the cheapest possible dies that will make them properly should be selected. If large quantities are to be produced, and especially if they must be very uniform in dimensions, it is economy to make the dies as perfect as possible in every detail; furthermore, they should be made of such design that the parts most liable to wear can be replaced, and thus avoid making entirely new dies. Sometimes, to lessen the risk of cracking and to allow straightening the dies, so-called *composite-steel bars* are used; these bars are soft iron for two-thirds of their thickness, while the other one-third is of steel and welded on.

25. Clearance of Dies.—Another point to be decided in the case of cutting dies is how closely they shall fit each other. The fit of a punch and die is important for two reasons. A tight-fitting punch will cause a burr on the blank and if the punch is fitted snugly in the die, its weak corners or points may be broken. Again, if the punch fits too loosely, the work

turned out will not be true to size, and will be burred. Assume that a punch in the shape of a star, Fig. 12 (*a*), is made to fit snugly the die *a*, Fig. 12 (*b*), and it is desired to punch blanks from $\frac{1}{4}$-inch steel or brass. The punch will then cut a hole in the stock equal to the size of the die. A very tight fit of the stock *b* will thus be caused on the punch. As the punch rises and the stock comes in contact with the under side of the stripper *c*, the stripper not being absolutely at right angles to the travel of the punch, there is a binding action on the punch at *d*, and with $\frac{1}{4}$-inch stock the points of the punch are very apt to be broken off. It follows that a certain amount of clearance between the punch and die must be provided. The following rule is applicable to practically all metals. It has been found to work well in practice.

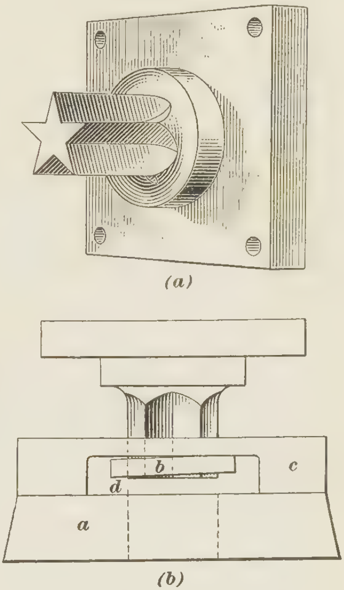


FIG. 12

Rule.—*For clearance between punches and dies used for blanking metal, make the size of the punch less than the size of the die by an amount equal to 6 per cent. of the thickness of the stock to be punched.*

EXAMPLE.—What clearance should be allowed between the punch and the die, when the stock to be punched is $\frac{1}{4}$-inch thick?

SOLUTION.—Since 6 per cent. of $\frac{1}{4}$ in. is .015 in., allow .015 in., say $\frac{1}{64}$ in., clearance between the punch and the die. Ans.

In this case, if a round punch is used its diameter will be $\frac{1}{64}$ inch less than the diameter of the die. If the punch is square, the length of one of its sides will be $\frac{1}{64}$ inch less than the length of one of the sides of the die.

CUTTING DIES

FORMS OF CUTTING DIES

26. Cutting dies may be subdivided into the following six divisions: *blanking*, *shaving*, *gang*, *progressive*, *compound*, and *subpress*.

The plain **blanking die** is used to cut out flat pieces of stock. For close work a second blanking die, called a **shaving die**, is sometimes used to take a light finish cut.

Gang cutting dies are those in which a group of similar punches and dies are fastened to their respective plates in such a way that several blanks are punched out at the same stroke of the press.

Progressive cutting dies, also called *follow*, or *tandem*, *cutting dies*, are those in which one part of the die is punching out the hole in the stock while another part is blanking out another piece. Two operations are performed on the same strip of stock at each stroke, but on different pieces of work. Hence, a finished piece is turned out at each stroke of the press.

Compound cutting dies are those in which both the upper and the lower half of the complete tool contains a punch and blanking die. Two operations are completed on the same piece at each stroke. A finished piece is turned out at each stroke of the press.

Subpress cutting dies are those which use a subpress for blanking, piercing, or blanking and piercing the work. Subpress dies may also be used for shaping or for shaping combined with cutting. In this case they would be classed as *subpress shaping dies* or *subpress combination dies*. Subpress dies, however, are not generally used for shaping or combination operations.

PLAIN BLANKING DIES

27. The **plain blanking die** shown in Fig. 13 is made up of four parts, which are: the hardened and tempered block *a*, called the *die;* the *stripper plate b*, which strips the stock from

the punch; the *guide strip c*, which guides the stock; and the *gauge pin d*, which gauges the location of the holes punched in the stock. By *stock* is here meant the material to be punched,

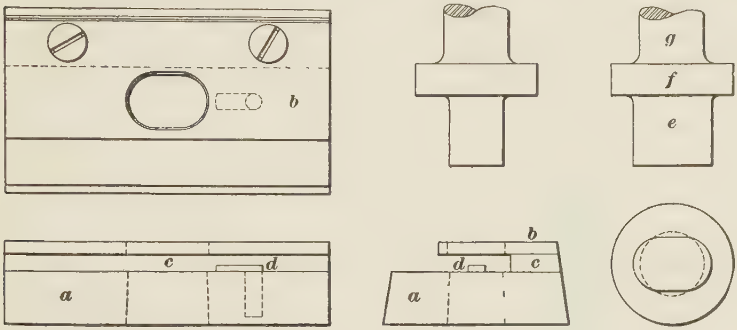
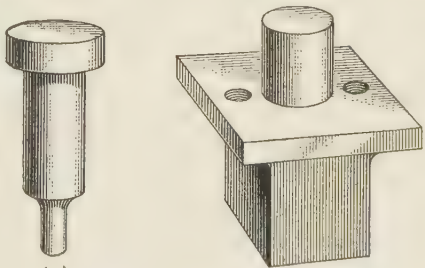


FIG. 13

which generally comes in long parallel strips and is fed by hand or automatically.

The **punch** has three parts, which are: the *punch* proper *e*, the *collar f*, which takes the thrust; and the *shank g*, by means of which the punch is attached to the ram of the press. These three parts may be one piece, as shown, or they may be separate pieces united to form the punch.

A **piercing punch,** illustrated in Fig. 14 (*a*), is a punch for making a hole of given shape through the stock, the *punching* being the material that is cut out of the stock. When the punching is waste material it is commonly called *scrap*. A **blanking punch,** illustrated in Fig. 14 (*b*), is a punch for cutting an article out of the material, the punching being the piece desired, called the *blank*.



(*a*) FIG. 14 (*b*)

28. Locating Punch.—Dies intended chiefly for producing holes do not always need a gauge pin. The material in which

the holes are to be punched is often center-punched at the point at which the hole is to be located. In that case, a locating punch, Fig. 15, provided with a small conical point *a* which enters the center-punch mark and thus centers the work is used. When holes are to be punched equidistant, a gauge pin will in many cases be found of great advantage, inasmuch as by its use the laying out of the holes on the work can be avoided. The conditions that exist in each case will readily determine whether a gauge pin can advantageously be used.

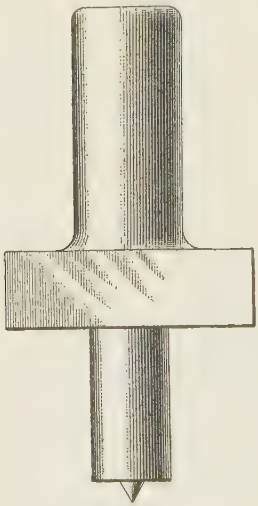


Fig. 15

29. Spiral Punch.—The spiral punch, illustrated in Fig. 16, is a punch which has its cutting edge *a* made in two or more spiral curves, instead of being in a single plane, as in the locating punch. This curved edge is intended to make it cut more easily; but with a small hole in thick metal the effect cannot be very great. The *dip* or *shear* given to large punches working in thin sheets enables the punch to come into action gradually; that is, one side begins to cut before the other. This punch is very cheaply mounted by the shank *b* and coupling *c*, which can also be used to hold any number of other punches. It is of a shape that is cheaply made and has in it the least possible material. In Fig. 16 the work is shown at *d*, the stripper plate at *e*, and the die at *f*.

30. Gauge Die.—A piece already punched may have other punching done within the space enclosed by its bounding edges by means of a second die, thus accomplishing the required result in two separate operations. The dies for the second operation on the same blank may be arranged as shown in Fig. 17, the die shown being an example of a gauge die. The punching turned out by the first operation is shown at (*a*); this blank is to be pierced by the holes *a* and *a*′, shown at (*b*).

The die is provided with properly located holes of correct diameter and the punch plate is furnished with two punches, as b and b'. The sectional view of the die is taken on the line $A\ B$. The guide strip and the gauge pin of the first operation die are here replaced by a *gauge plate c* attached to the die. This plate is fastened in such a position that it will properly locate the blank in relation to the holes in the die.

The gauge plate has an opening of the same shape as the blank, but sufficiently larger to allow it to be freely inserted. If a stripper is attached to the die, it will not only be difficult to insert the blank in the gauge plate, but it will also be difficult to remove it. It is also difficult to keep clean the opening in the gauge plate. To overcome these objections, the stripper d may be fitted to the punch; it is attached by means of two heavy screws e, which permit it to move upwards. Heavy coiled springs f hold the stripper in its lowest position, which is so governed by the length of the screws that its lowest surface projects slightly beyond the faces of the punches.

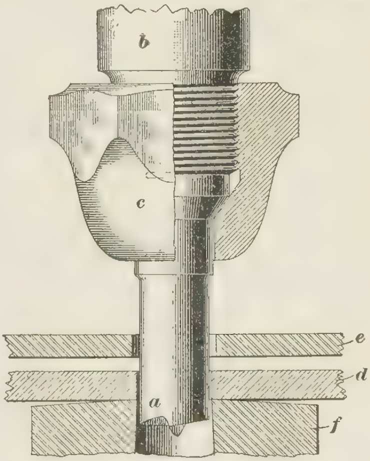


FIG. 16

31. Imagine the die to be in place and that a blank is placed in the opening j of the gauge plate. Then, if the punch descends, the stripper comes in contact with the blank and remains stationary. As the punch continues to descend, the coiled springs are compressed; the punches pass through the blank, and when they return, the springs, by acting on the stripper, strip the blank from the punches.

In order that the gauge plate may not shift, it is doweled to the die by means of the dowel-pins g, and is held down by flat-headed or fillister-headed screws. To allow the blank

to be readily removed from the gauge plate, a part of the circumference of the opening may be beveled, as shown at *h*. A wedge can then be used for prying out the blank. The gauge plate is often so made that it encircles about one-half the blank, which is then pushed against the gauge and after the

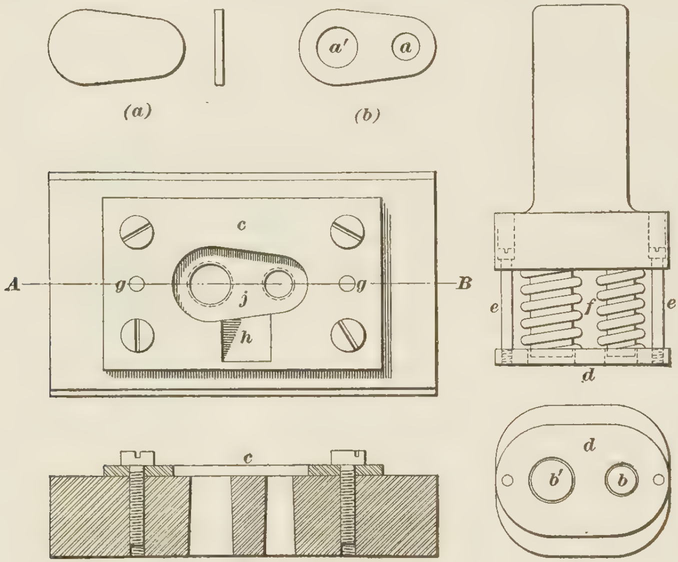


FIG. 17

blank is punched it can be removed by being slipped out. This arrangement is somewhat objectionable on account of the liability of the blanks moving slightly away from the gauge before the punch strikes it. For rapid work or if blanks are to be made in quantities this type of die is not used.

PROGRESSIVE AND GANG CUTTING DIES

32. Progressive and gang cutting dies are used to reduce the time required to do the work. Some designs are, however, open to the objection that, while they accomplish their primary object, they cannot be relied on to produce duplicate work since they depend largely on the straightness of the stock and the skill of the press operator to produce good work.

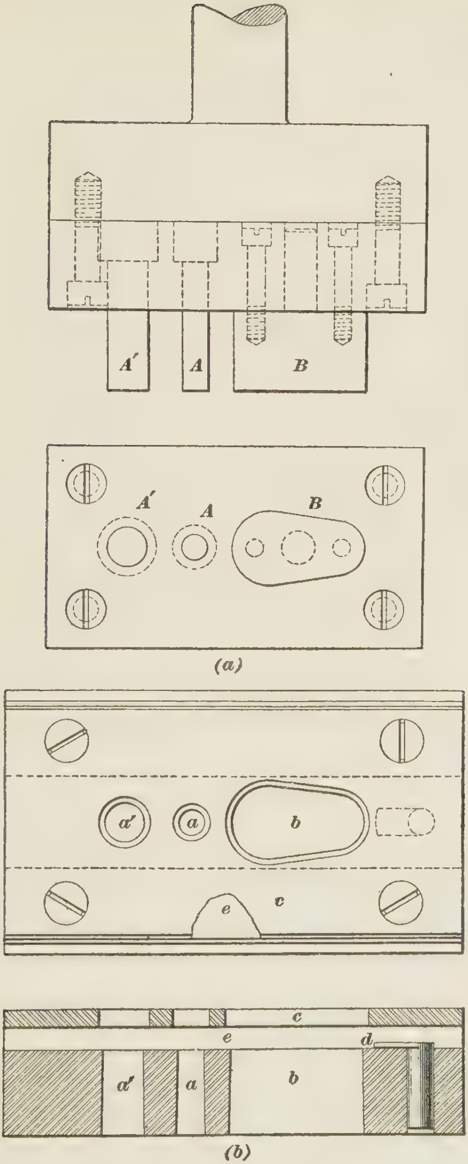


Fig. 18

33. Ordinary Progressive Cutting Dies.—A common design of progressive cutting die is shown in Fig. 18, which is arranged to punch the piece shown in Fig. 17 (*b*). For this purpose, the die, Fig. 18 (*b*), contains three holes: *a* and *a'* are for punching the holes within the blank and *b* for punching the blank itself. The stripper is shown at *c* and the gauge pin at *d*. Two guide strips *e* guide the stock between them. When starting, a strip of stock is inserted at the left of the die, below the stripper, and pushed forwards until its end is a short distance beyond the left-hand edge of the die *b*. The piercing punches *A* and *A'*, Fig. 18 (*a*), then punch the holes in the first piece. As the stock extends over the edge of the die *b*, the blanking punch *B* will trim off the edge even

with the die. The stock is pushed forwards till its right-hand edge comes against the gauge pin *d* in (*b*). On the next stroke of the press, the first piece will be blanked and the holes in the second piece pierced. The stock is then pushed along until the left-hand edge of the large punched hole in the stock comes against the gauge pin. The holes *a* and *a'* in the stock are now in their correct positions above the opening *b* in the die; as the punch descends, it cuts out a finished punching at *b*, and at the same time cuts a new pair of holes *a* and *a'* through the stock. Assuming that the die is correctly laid out and the gauge pin accurately located, it is readily seen that if the operator fails to push the stock against the gauge pin, the holes will not be correctly located in the blank. Hence, although when in skilled hands, this design will produce fairly accurate work, it cannot be relied on to make exact duplicate pieces. Whether this consideration is of sufficient moment to prevent its use must be decided upon the merits of each case.

In Fig. 18, two guide strips are placed the required distance apart to insure the stock being properly fed in; these strips can be used, however, only when the stock is uniform in width and straight. When it is not, only one guide strip can be used, and the operator must always push the stock firmly against it. Should he fail to do this, the holes will be improperly located in some of the punchings.

In some cases one of the guides has springs back of it, which hold it against the stock, which is held against the other guide.

34. Self-Locating, Progressive Cutting Dies.—Self-locating progressive dies, illustrated in Fig. 19, are intended to overcome, to a large extent, the defects of ordinary progressive dies. The piece to be punched is shown at (*a*), the die is shown at (*b*), and the punch at (*c*). In order that the stock may be properly centered in case the operator should fail to push it against the gauge pin, the punch is provided with a beveled pilot pin *a*. The upper part of the pin is made an easy fit in the circular hole already punched in the stock and is so located on the punch *c* that its center line coincides with the center of the hole in the stock.

This style of die will produce duplicate work within quite a small limit of variation. This limit, within which the holes will be located, is equal to the difference between the diameters of the pin and the hole. The design shown is, however, open to one objection. Should the punch come down when the stock is so placed that the pin is not fairly over a hole, the pin is pretty sure to be broken. But this objection may, under certain circumstances, be overcome by making the pin movable in an axial direction and providing a helical spring that will be compressed by the receding of the pin in case it strikes solid stock.

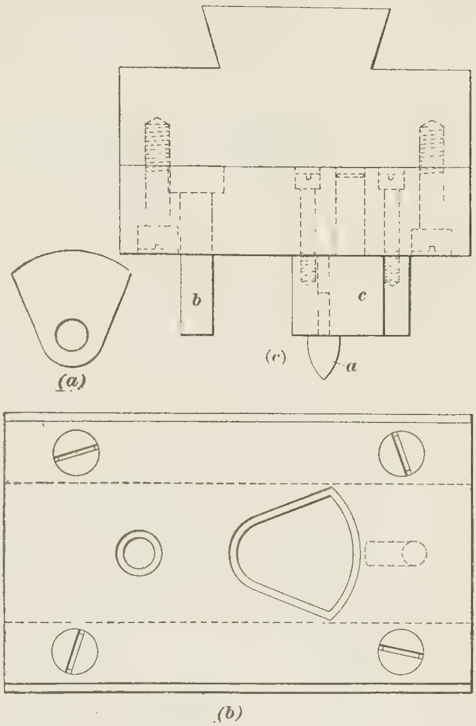


Fig. 19

35. Inaccuracies in Progressive Dies.—When stock is punched with progressive dies inaccuracies may appear in the blanks. One cause for inaccuracy is that the stock does not lie flat on the die. By referring to Fig. 20, it will be evident that, if the wrinkled stock *a*, which is shown greatly exaggerated were perforated with punches *b* and *b′*, the holes would be too far apart when the stock is straightened. If the stock is

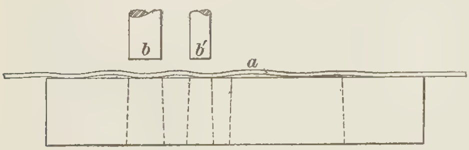


Fig. 20

blanked after it is pierced as just described, the holes in the blanks will be closer to the ends than is desired, owing to the fact that the stock is straight when the blanking punch is in contact with it and returns to its curved state after the blanking.

36. A progressive die that will produce fairly accurate results is illustrated in Fig. 21. The essential difference between

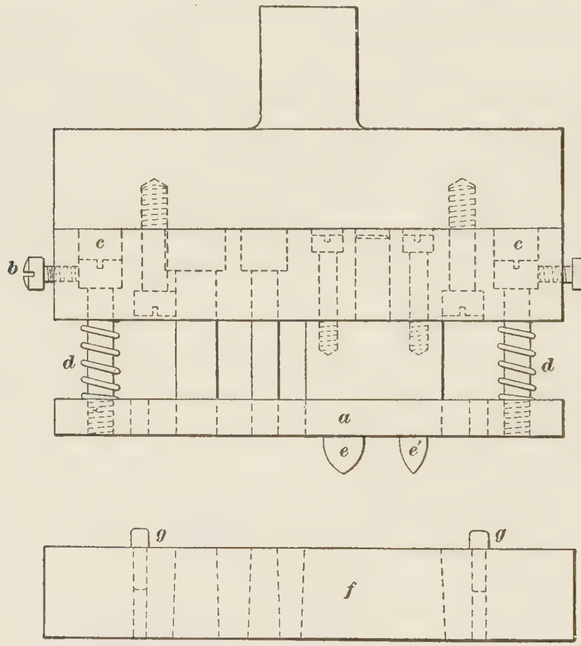


FIG. 21

this die and the one shown in Fig. 19 is that a spring-supported stripper *a* is used. The screws *b* are employed only in setting up. The studs *d* supporting the stripper are adjustable in slots *c*, being held in the desired position by the screws *b*. When setting up the punch and die, the stripper is raised until the punches project beyond it, otherwise it would be difficult to tell when the punch lined with the die. After the punch is located in line with the die, the stripper is set so that it will

extend downwards a little beyond the ends of the punches. The pins *g* are for guiding the stock. The stripper comes in contact with the stock and flattens it against the die *f* before the piercing is done, and the work springs back to its curved state when the stripper rises. Before blanking, the pilots *e* and *e'* of the blanking punch locate the work and the stripper flattens out the stock. Without the spring stripper to flatten the stock before it is pierced, the pilots in the blanking punch would distort the holes in the blank.

37. Gang Cutting Dies.—Gang cutting dies differ from progressive cutting dies in that the former are used to blank several like pieces at each stroke, whereas the latter are employed to pierce one piece at each stroke and at the same time to blank the piece pierced at the previous stroke of the press.

COMPOUND CUTTING DIES

38. Construction.—Compound dies, shown in Fig. 22, are used when punchings containing holes must be exact duplicates. These dies differ from those already described in that both the upper and lower parts have a punch, die, and stripper. The lower part, shown in (*a*), contains the blanking punch *a* and the piercing dies *n*. The upper part, shown in (*b*), contains the blanking die *A* and the piercing punches *I*. In operation the upper and lower parts fit into each other and produce an exact duplicate blank at each stroke.

In (*a*) is shown a vertical section and a plan view of the lower die; at (*b*) is illustrated a vertical section and a bottom view of the upper die; while at (*c*) is shown the complete punching, which is produced in one operation. Referring to (*a*), the tool-steel block shown at *a* is both a die and a punch. It is fitted to a recess cut into the plate *b* and is attached to it by means of the screws shown. The block *a* is surrounded by the stripper *c*, which is free to move up and down. The uppermost position of the stripper plate is reached when the heads of the screws *d* butt against the plate *b*. The stripper is held up by heavy helical springs *e*. The guide strip *f* and

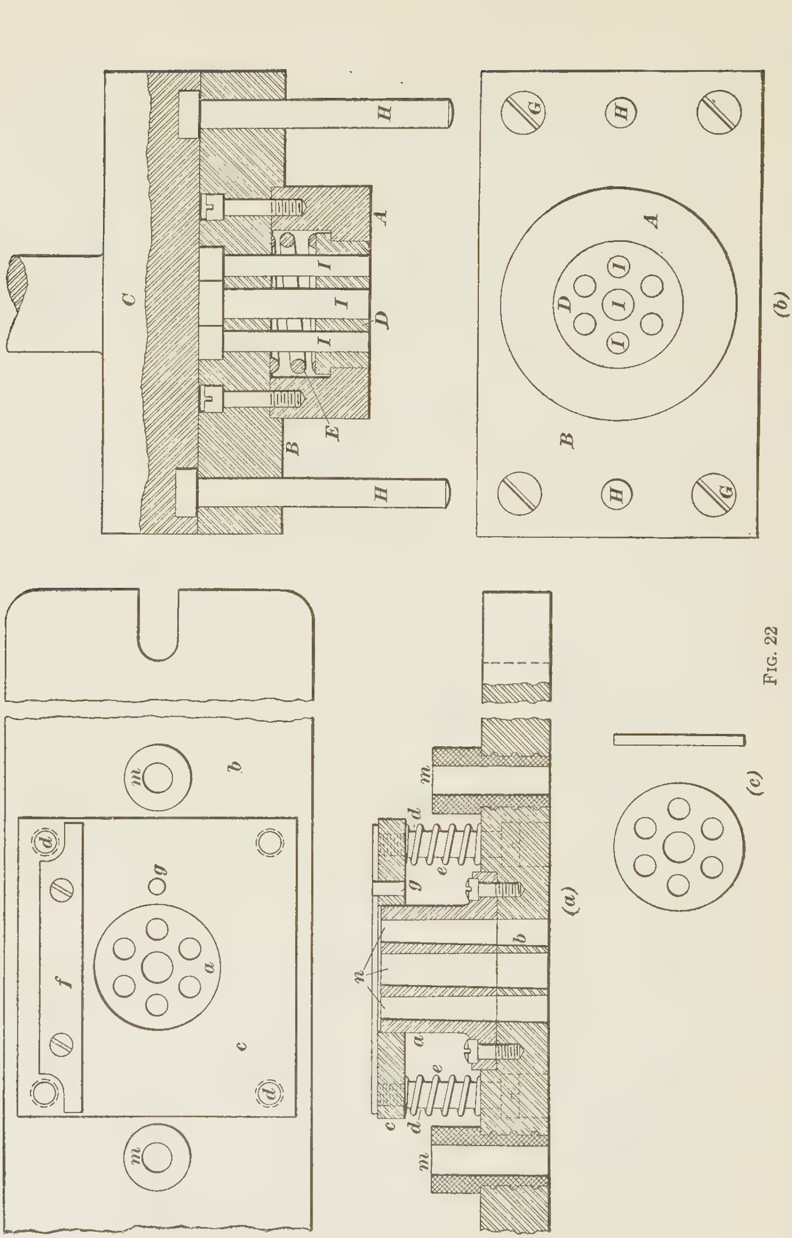


Fig. 22

gauge pin g are fastened to the stripper. The guide pins H of the upper part fit in the bushings m.

In the upper die, shown in (b), the blanking die A and the piercing punches I are each rigidly fastened to the punch plate B, which is secured to the punch holder C by the screws G. The stripper D fits in the blanking-die block and surrounds the punches; it is axially movable, being confined as to its lowest position by a shoulder and held down by the helical spring E, which in this particular case surrounds the punches. The outside of a in (a) fits the inside of A in (b), and the punches I, in (b), fit the holes n in (a).

39. To reduce the dulling effect caused by the punches entering the dies, the press is so adjusted that the punches will not enter the dies but will only force the scrap and blank into and flush with the top of their respective dies. The guide pins H are necessary to guide the parts, when setting up the die in the press, as they prevent shearing. They are made perfectly straight. When in place in the punch plate, the punches are entered in their dies and the molten Babbitt is poured around the pins H forming the bushings m. The bushings will then fit the pins. When the bushings are made of steel both the bushings and pins are hardened and ground. This type of die is expensive, owing to the time required for the accurate tool-making work needed. The cost of making is, however, more than offset by the saving effected when the die is used for making large quantities of duplicate pieces.

40. Operation.—The stock having been placed against the guide and the gauge pin, the upper part of the die, in descending, first depresses the lower stripper c, Fig. 22 (a), until the stock touches the upper surface of a. As the upper part continues to descend, it punches the outside of the punching and the inside holes at the same time; the blank passes into the upper die, pushing the stripper D, in (b), upwards. When the upper part moves up again, the lower stripper c, under the influence of its springs, strips the stock from a; at the same time, the upper stripper D ejects the blank from the upper die, forcing it part way back in the stock before the dies separate. By

adjusting the tension of the springs the blanks can be forced back in the stock just far enough to be held, from which point they may be easily shaken. The scrap punched from the blank passes down through the piercing dies *n* in the lower part. The dies *n* are given a slight clearance to facilitate the descent of the scrap. No clearance is provided in the blanking die *A*, as the blank enters only a very short distance.

SUBPRESS CUTTING DIES

41. Subpress and compound dies are very similar in principle. For small blanking and piercing work that must be turned out accurately and quickly the alinement of the upper and lower parts of the die must be more perfect than can be obtained in an ordinary press. A subpress is a supplementary press that blanks and pierces small work accurately at each stroke. The base of the subpress is clamped to the bed or the bolster plate and the plunger head, or button, is connected to the ram of the main press. Subpresses can be made to take several sets of punches and dies, but a separate subpress is generally made for each set of dies. Subpresses are used extensively by watch and clock manufacturers. The description, together with the making of a subpress die, is given in *Dies and Die Making*, Part 2.

LAYING OUT DIES

42. Economy in Use of Stock.—Before a die is laid out—that is, before the outline of the hole and the exact location of the gauge pin can be marked on the surface of the lower die—the most economical way of punching the stock must be determined. Then, the die must be laid out so that the greatest number of punchings can be obtained from a given weight of stock, in order to reduce the waste to the lowest figure. This matter requires a great deal of judgment. A good plan is to cut a few pieces of paper to the required outline of the punching; then, by arranging them in different ways, the most economical system may be determined.

Cases illustrating right and wrong ways of punching stock are shown in Fig. 23, where a represents the stock and b the holes remaining after the punching has been done. In (a), a method of punching out stock that leaves an enormous amount of waste is shown. In (b) the gauge pin was so located that there was sufficient stock left between each pair of holes, after passing the strip entirely through the press, to allow it to be reversed and passed through once more, punching out most of the metal that remained between the holes after the first punch-

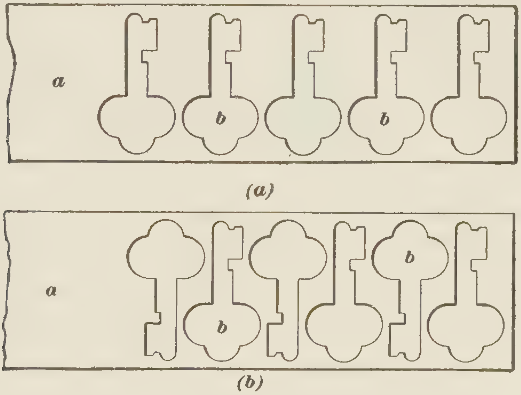


FIG. 23

ing. By arranging the operations to take place as in (b), a great many more punchings can be obtained.

An appreciable economy can often be obtained by the judicious selection of a proper width of stock. Thus, in Fig. 24, supposing a to represent the stock, and b the holes left after punching, it can be seen that by using stock wide enough to punch staggered holes, as in (b), less material will be required for a given number of punchings than is needed when using a narrow strip, as in (a). By measuring, it will be seen that the wide stock is not twice as wide as the narrow, although it will practically give twice the number of punchings for equal lengths of strips. Paper or tin-plate models having the required outline can also be used advantageously for finding the best width of stock.

43. Position of Gauge Pin.—The part of the gauge pin that forms the stop for the stock determines by its position the amount of stock that remains between the punched holes. This amount at the narrowest point between adjacent holes should, in general, not be less than the thickness of the stock and may be slightly more for very thin material. It should not be forgotten that the punch, in passing through the stock, tends to draw, and actually does draw, some of the surrounding material toward its cutting edges. If there is too little stock around the periphery, ragged punching is apt to result.

44. Shear of Dies.—When the face of a punch or die is so formed that one part of the edge commences to cut in advance

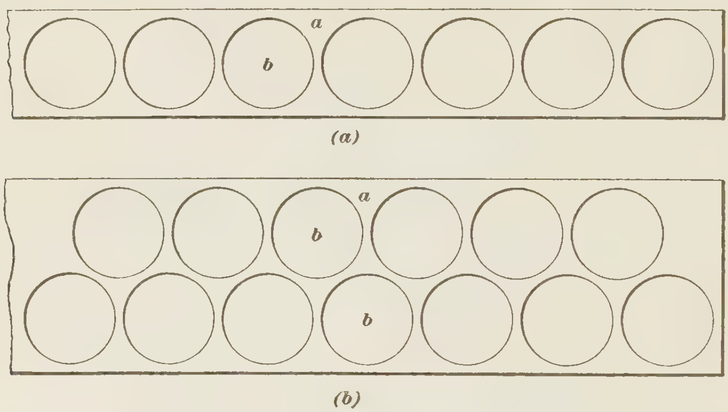


FIG. 24

of other parts, it is said to have **shear**, as in the case of the spiral punch, Fig. 16. The object of giving shear is most commonly the reduction in the force required to do the punching; in other words, shear allows a press of a given capacity to punch work for which ordinarily it would not be sufficiently powerful. Shear may be given either to the die or to the punch, or even to both.

A common way of giving shear to the die is shown in Fig. 25, which is a vertical section. The punch is flat at its cutting end. In coming down on the stock, cutting will commence at *a* and proceed toward *b* and *c* at the same time. If the punch has a

shear the reverse of that on the die, the shear will be doubled. Dies intended to have shear are usually made with a raised boss around the opening, as shown in the illustration. They are then more easily sharpened.

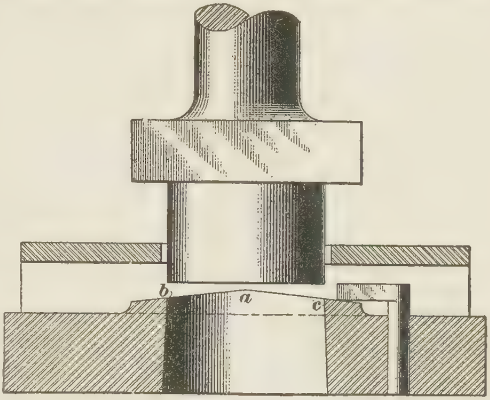


Fig. 25

45. Sometimes the effect of shear may be obtained in other ways. Thus, in Fig. 26, where several holes are to be punched in one operation, each punch may be made longer than the one next to it on the left. Then, if their difference in length is made slightly greater than the thickness of the stock to be punched the right-hand punch will have completely passed through the stock before the middle one comes down on it, thus leaving the power of the press available for each successive cut.

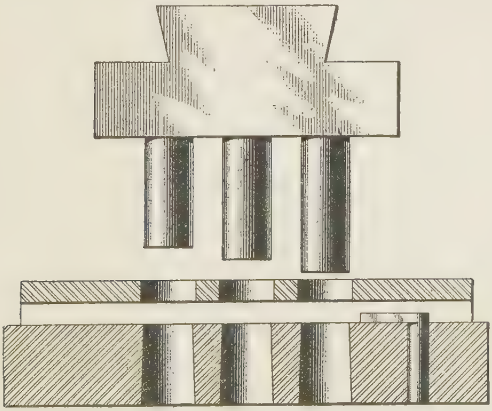


Fig. 26

When the effect of shear is obtained as in Fig. 26, neither the punching nor the stock will be bent; if the shear is obtained as in Fig. 25, the stock that is being punched will come out bent, but the punching will remain almost flat. If the shear is given to the punch and the die is left flat, the punching will come out crooked, but the stock will be left flat.

If both punch and die block have shear, usually both the stock and the punching will come out crooked. From these considerations, the toolmaker must determine the construction for each particular case.

MAKING PLAIN BLANKING DIES

46. Let it be required to make the plain blanking die shown in Fig. 13. The die block is first cut off the desired length, and planed all over, making its width fit the die shoe and taking at least $\frac{1}{16}$ inch of stock from the top or cutting face. The top face is then planed smooth to partly prepare the surface for the laying-out process, after which the top is polished either with emery cloth or by grinding. It is then placed on a hot plate or over a fire, and dipped in oil when a deep-blue color appears. This is done to check and hold the color. A quicker way to blue the top of the die block is to clean the surface of oil, and then wipe it with a piece of waste or a rag dipped in a blue-vitriol solution, which is made by mixing one part of copper sulphate with ten parts of water. This solution produces a bright copper color, but when machining or filing the steel the copper surface will peel off. Where there is to be considerable filing or machining on the die, the blue surface produced by heat will be found far superior.

47. With a surface gauge having a very fine point, a fine center line is scribed in the middle of the top of the block *a*, Fig. 27 (*a*). By referring to the working drawing, (*b*), the length of die is found to be $\frac{3}{4}$ inch. Two lines *b b* and *b′ b′*, in (*a*), are scribed with a surface gauge $\frac{3}{4}$ inch apart on the die block. The dividers are next carefully set to $\frac{1}{4}$ inch and $\frac{1}{2}$-inch circles are scribed on the face, the centers of the circles being on the center line in (*c*) and the circles just touching the lines *b b* and *b′ b′*. The centers of the circles are prick punched lightly with a fine-pointed prick punch. The lines *e e′* are now scribed tangent to these circles, and the block is clamped on the lathe face plate, setting the block so that one of the centers runs true, as shown by the machinist's indicator. The hole is now spotted, drilled, and bored to size, allowing a clearance of

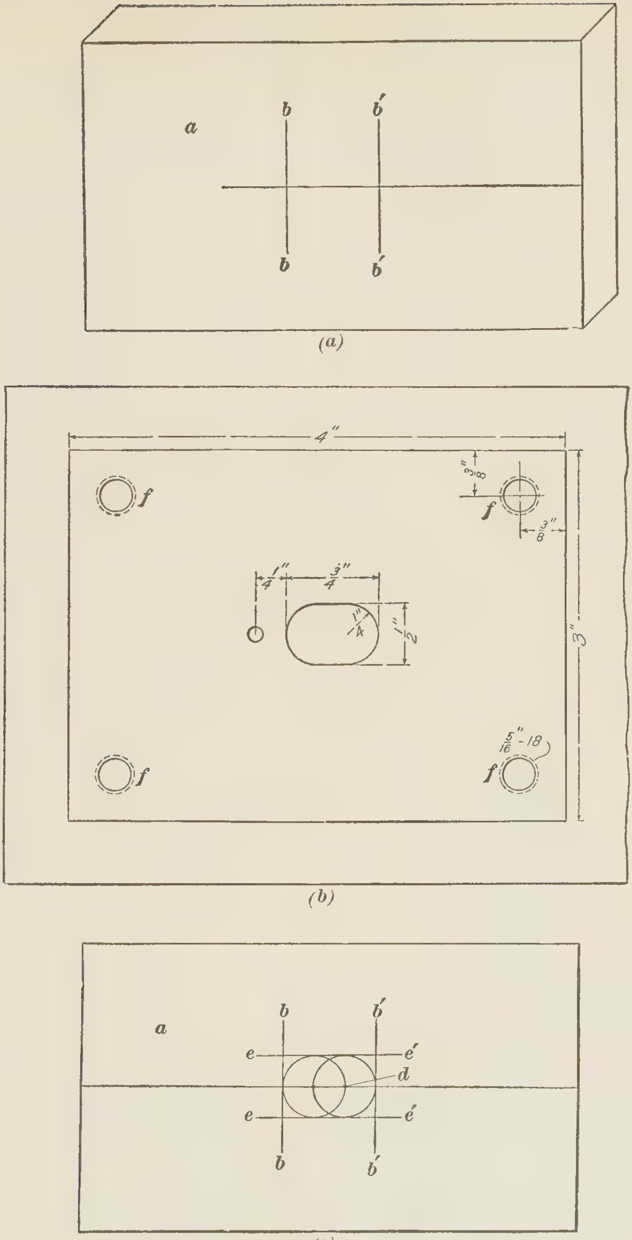


FIG. 27

about $\frac{1}{2}°$, which is obtained by setting the slide rest at an angle. The block is then set so that the other center runs true, and the other hole is machined as before.

48. After boring both holes, the web remaining between the two holes is filed to the lines *e e'*. The die is held in a pair of parallel clamps, which are, in turn, held in the vise, and rough filed as shown in Fig. 28. Filing vertically enables the toolmaker to readily see the lines on the face of the die. The metal is removed from the side of the die next the vise. A small die gauge, or die square, having the proper angles for clearance is frequently used to make sure that the clearance is being properly filed. After the die has been filed very close to the lines, it is held in the vise for finishing as shown in Fig. 29. However expert a toolmaker may become in filing dies, it will be found, after roughing, that the filed surface is slightly rounding in the center. Holding the die as shown enables the toolmaker to see inside when filing the high places in the center.

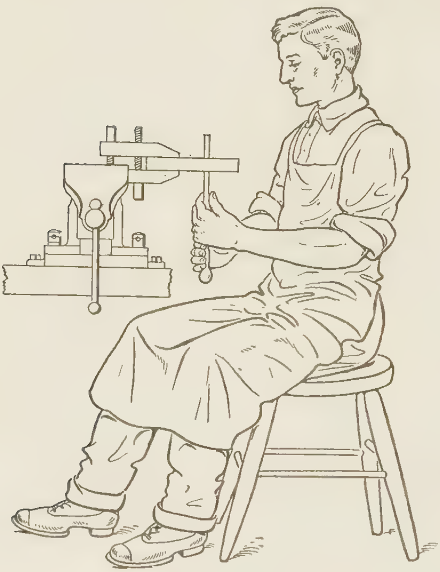


Fig. 28

49. Working From Templet.—Generally dies are made to fit a templet or model furnished. Let it be required to make a die for the blank indicated by the bounding lines of Fig. 31, a templet being supplied. The templet is laid on the die, which has been previously blued, and held securely by a die clamp, as shown in Fig. 30 (*a*) and (*b*). In the figures *a* is the die, *b* the clamp, *c* the templet, and *d* the adjusting screw. A fine,

deep line is scribed around the templet on the die block. After the clamp is removed, a short rod for a handle is soldered to the side of the templet for convenience in future use. Holes are then drilled around the scribed lines, Fig. 31, care being taken that the holes do not touch the lines. The end holes are drilled in a lathe and bored for clearance. A hardened broach, Fig. 32, is used to cut away the webs between the holes. This is accomplished by placing the broach centrally, first on the top and then on the bottom of the webs, and driving it part way through the die with a hammer. Fig. 33 shows the web *a* after the broach has been driven in from the top and bottom. The web *b* is yet to be cut out.

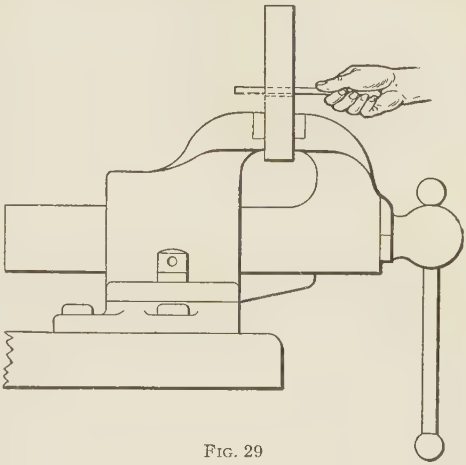


FIG. 29

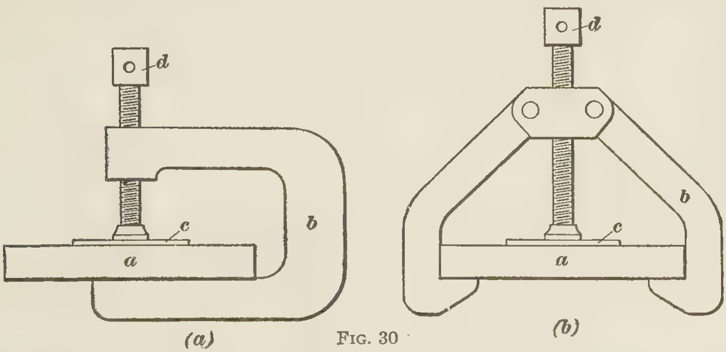


FIG. 30

50. If a jig saw, or a filing machine is at hand, the end holes only are put in the die. A saw blade is then put through the hole in the die with its teeth pointing down, each end being

secured to the machine. Narrow saws are made especially for die work. By tilting, to the proper amount, the table of the machine on which the die rests, the portion inside the lines can be sawed out with the proper clearance. A file may then be put in the machine, with its teeth pointing up, and the die filed very close to the lines. After making sure that the clearance angle is correct, the die is fitted to the templet by hand filing, as shown in Fig. 29. The templet is held by its handle and inserted in the opening at the bottom of the die, as illustrated in Fig. 34, in which a is the die, b the die face, and c the templet. By looking through the opening, after starting the templet, it will be noticed that the templet touches only in spots. These points of contact are marked with a lead pencil and they only are filed. By inserting the templet again it will be noticed that it enters a trifle farther than at first. By continuing this process, the die is easily made to fit the templet by the time the templet reaches the face of the die.

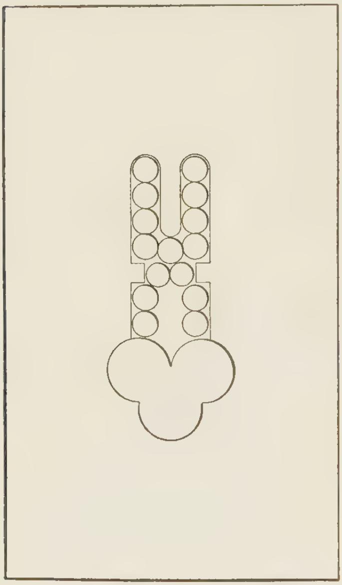


Fig. 31

51. Concaving of Dies. If the clearance in the die is only one-half of 1°—which is ample as it allows considerable grinding on the face of the die without materially enlarging the blank—the die should be scraped slightly concave, as shown in Fig. 35 (a). The concave need not be more than .002 inch deep. Concaving is necessary because of the bulging that takes place when hardening the die. The outer surface contracts before the red-hot interior and the compression causes a slight bulging in the opening, as shown in Fig. 35 (b). If the die has only a small clearance, the bulging will prevent the blanks from readily passing through, causing burrs if the blanks are strong and

both burrs and distortion if they are weak. The ends of the die being semicircular, boring the holes tapering will produce

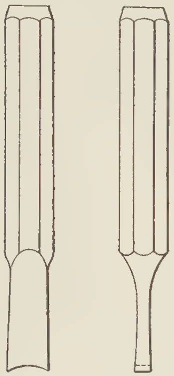


FIG. 32

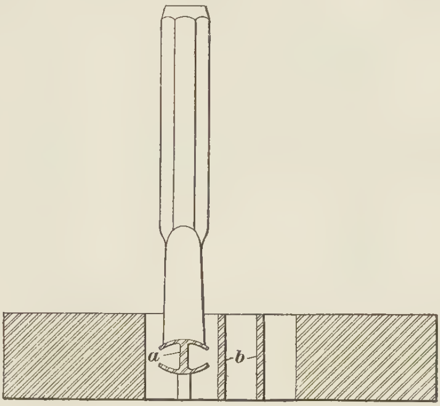


FIG. 33

a true radius on each end. If, however, the holes were drilled or counterbored in a drill press, then reamed to a taper or filed to give clearance there would be no assurance that the drill, counterbore, reamer, or file had run entirely true. The length of the die may have also been changed.

52. Finishing Dies.—The gauge and stripper holes, and the holes *f*, Fig. 27 (*b*), for holding the die to the die shoe, may be drilled in a drill press, and tapped by hand. After tapping the holes the die is ready to be hardened and tempered. After tempering, the oil is thoroughly removed, preparatory to grinding, to prevent the clogging of the emery wheel, which would tend to burn the cutting edges. The bottom of the die is ground first; then the top or face of the die is ground until a keen edge is obtained. Care must be exercised or the edges will be heated.

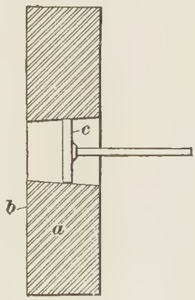


FIG. 34

53. Making Punches.—As a plain die needs but one punch, it is customary to have a holder that fits the press to which the punches are fitted. The shank *c*, Fig. 36, is turned

to fit the holder and the face of the punch is blued. A line is scribed both lengthwise and crosswise on the face of the punch so that the intersection will be approximately central. The punch is now ready to be laid out. Using the die clamp, shown in Fig. 30, the face of the punch is clamped against

(a) FIG. 35 (b)

the face of the die so that the cross-lines appear central when looking through the die, and the outline of the die is traced on the punch with a fine-pointed scriber. The shank of the punch is held in the chuck on the dividing head of the milling machine and milled as close as possible to the lines without cutting away any of them. A round corner should be left at *a*, Fig. 36, to provide for stiffness and guard against cracks.

54. Fitting Punches.—The corner *b*, Fig. 36, is beveled slightly with a fine file to aid the punch starting in the die. The punch is forced into the die $\frac{1}{64}$ inch. The die will shave the punch, giving it the exact shape of the die. The stock on the punch is now removed either by careful milling, chipping, filing, or scraping. If much stock is to be removed, it is best to mill. By repeated shearing of the punch and removal of the chip raised by the die, the punch is fitted so that it will enter the die, say $\frac{3}{4}$ inch.

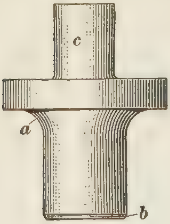


FIG. 36

55. Relieving Punches.—The punch is now the same size as the die, and proper clearance must be provided between the punch and die. This process is known as **relieving.** The amount of clearance is determined by the rule of Art **25.** On regularly shaped punches no difficulty will be experienced in relieving the punch. On irregularly-shaped punches the following method may be used. The punch *b* is held in the holder *a*, Fig. 37, the base of which is free to slide on the table of the drill press. A fine-toothed mill *d*, held in the drill chuck *c*, is so made that the difference

between its diameter and the diameter of the roller *e* will be equal to the desired clearance. The roller *e* is held in place by the screw *f* and is removable. Hence, rollers of different sizes may be used on the same mill. The distance *g* must be a trifle less than the distance the punch has penetrated the die.

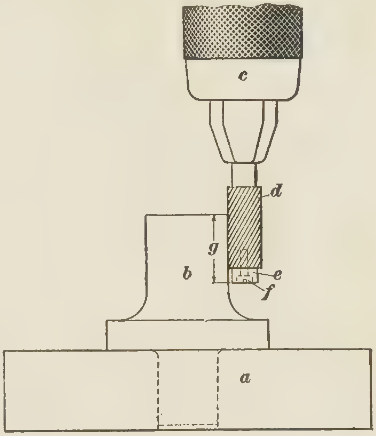


FIG. 37

56. In operation the punch is held against the rapidly revolving cutter until the roller bears against the punch. The part of the punch against which the roller bears must have been sized by the die. The punch is then slowly moved along until the cutter has removed the proper amount from the entire periphery. Punches may be relieved by careful filing. Many toolmakers become expert in relieving a punch by hand filing and prefer this method to the one just described. The punch is hardened and tempered after it has been relieved.

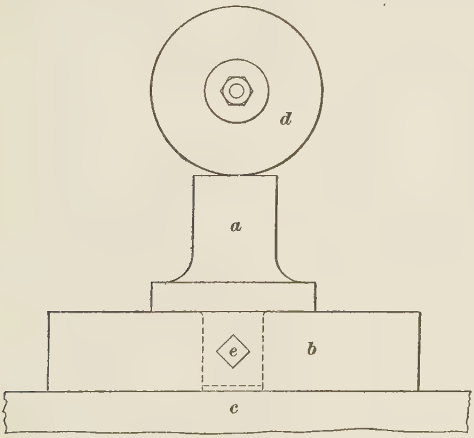


FIG. 38

57. Grinding Punches.—After being tempered, the punch is ground as shown in Fig. 38. The punch *a* is held in the holder *b* by the setscrew *e*, the holder being clamped to the bed *c* of the surface grinder. The grinding wheel *d* removes the stock as the table travels horizontally.

Care must be taken that a keen, sharp edge is obtained. If the beveled edge of the punch, Fig. 36, is not entirely removed a burr on the blank will result.

58. Strippers.—The thickness of the stripper depends on the thickness of stock to be punched. Consider the stripper shown in Fig. 39. If $\frac{1}{16}$-inch stock is to be punched, the thickness *a* of the stripper should be about $\frac{1}{4}$ inch. This thickness would allow a distance of $\frac{1}{8}$ inch between the under side *b* of the stripper and the die, leaving $\frac{1}{8}$ inch of metal in the stripper directly surrounding the punch. The stripper plate is first planed all over and then clamped to the die. The four corner holes *c* are now drilled, the die being used as a jig. After drilling in this way, a larger drill must be run through to permit the screws to enter.

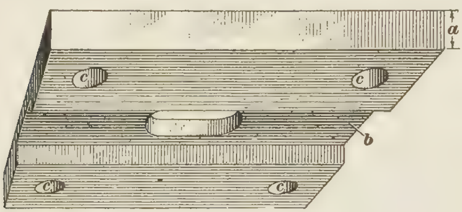


FIG. 39

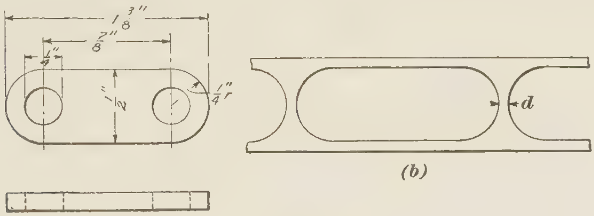
59. The stripper is now screwed to the die and the outline of the die scribed on the under side of the stripper. After its removal from the die, a pair of parallel lines are scribed the entire length of the stripper, the distance between the lines to be not more than $\frac{1}{64}$ inch wider than the strip to be punched. The opening in the stripper is now drilled out and filed $\frac{1}{16}$ inch larger than the die, thus leaving $\frac{1}{32}$-inch clearance all around the punch. The space between the parallel lines is planed out, the stop-pin put in the die, and the stripper secured to it. The die is now ready for use.

60. Setting Up Punch and Die in Press.—The toolmaker is frequently obliged to set up the punch and die in the press; for example, to get blanks to be used when making shaping dies. To do this, the punch is first securely fastened to the ram of the press; after which the die is clamped to the die shoe, which rests on the bed or bolster plate. The flywheel is then turned until the punch is lowered to within $\frac{1}{16}$ inch of the face

of the die. A short piece of wood is put up through the hole in the bed until it rests against the bottom of the die shoe. Placing one knee under the other end of the wooden stick, the die is raised from the bed and guided by both hands until the punch enters the die about $\frac{1}{4}$ inch, when the flywheel is turned, lowering the punch until the die shoe rests against the bed. The shoe is then bolted to the bed and the ram adjusted so that the punch just enters the die. The punch and die are now in readiness for operation. When the die and shoe are too heavy to be raised in this way or the construction of the press makes it impossible, other methods suited to the conditions must be devised.

MAKING PROGRESSIVE CUTTING DIES

61. Laying Out and Preparation of Stock for Punch Plate and Die.—Suppose that it is required to make a progressive die for punching the piece shown in Fig. 40 (*a*). It would be good practice to make the die as shown in Fig. 41.



(*a*) (*b*)

FIG. 40

The piercing dies *a* are made to punch the holes in the work, the blanking die *b* to cut out the blank, and the die *c* to cut out the web *d*, Fig. 40 (*b*), so that the stock may pass by the stop-pin to be described later. The web between the blanks is made $\frac{1}{16}$ inch, and the stock for the die is prepared as explained in Art. **46.** The punches in this case must be held in a punch plate. The punch plate is squared up to fit the punch holder and is doweled to the die so that it may be removed and returned exactly to its place when desired. The punch plate is removed and the die is ready to be laid out. The die block should have one straight and fairly smooth edge. A line *e*, Fig. 42, is scribed

lengthwise on the middle of the face of the die block and the approximate location of the piercing holes *f* and *g* and the die opening *b* are laid out roughly with a lead pencil, in order

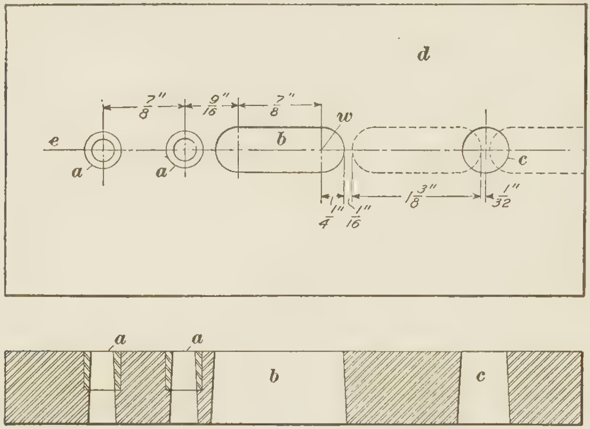


FIG. 41

that they will come somewhere near the center of the die block. The center *h* is prick-punched on the line *e* $\frac{1}{4}$ inch from the right-hand end of *b*.

62. Boring Blanking Die.—To bore the blanking die, the die block *i*, Fig. 43 (*a*), and the plates *j*, which are shown

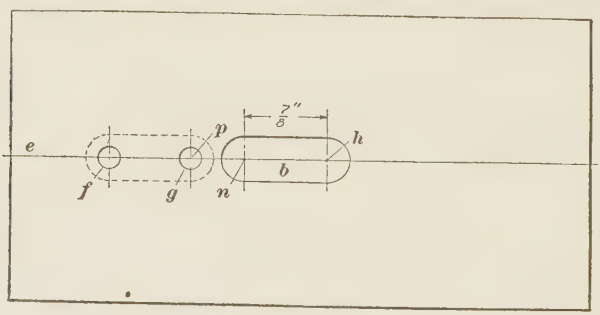


FIG. 42

in perspective in (*b*), are clamped to the lathe face plate, the die block being so set that the prick-punch mark *h* will run true as shown by a machinist's indicator. The screws *k* are adjusted

until they just touch the die block and they are then locked in position by the setscrews *l*. The die block is now spotted, and

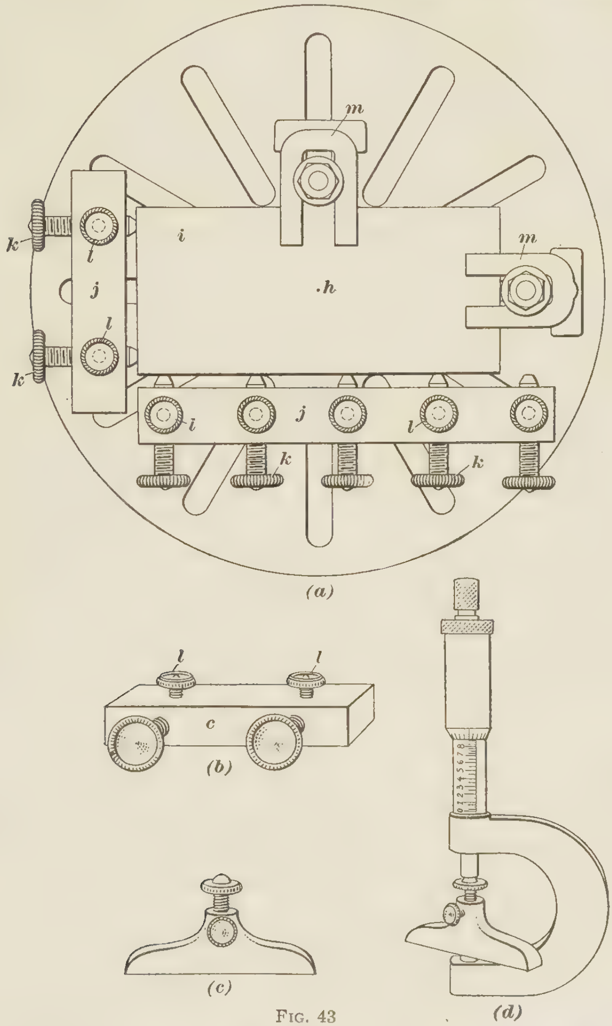


Fig. 43

drilled for a $\frac{1}{2}$-inch hole, after which, the compound rest being used, one end of the blanking die is formed by boring a $\frac{1}{2}$-inch hole, a clearance of about $\frac{1}{2}°$ being allowed. The adjustable

size block, Fig. 43 (*c*), is then set to $\frac{7}{8}$ inch by the use of a micrometer caliper, as shown in (*d*), and after loosening the clamps *m* in (*a*), the size block is placed against the screws *k*, as shown in Fig. 44. The die block is now held against the size block and the plate *j* and clamped to the lathe face plate, thus locating the center *n*, Fig. 42. A $\frac{1}{2}$-inch hole is now spotted, drilled, and bored with a clearance of $\frac{1}{2}°$, thus forming the other end of the blanking die. With this method, which is sufficiently accurate for progressive die work, the block has

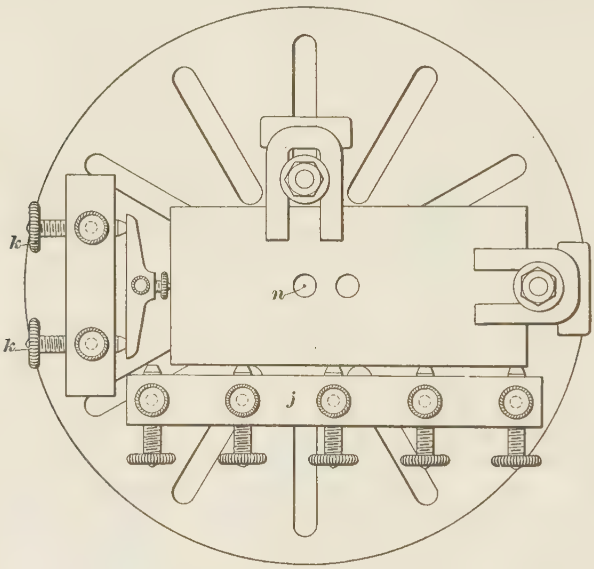


Fig. 44

been moved the proper distance and the holes are kept in a straight line.

63. Boring Piercing Holes.—The distance between the center *n* and the center *p* of the piercing die, Fig. 42, is $\frac{1}{4}+\frac{1}{16}+\frac{1}{4}=\frac{9}{16}$ inch, the thickness of the web being $\frac{1}{16}$ inch. The dotted profile of the blank shows the next blank to be cut by the blanking punch. The size block, as used in Fig. 44, is set for $\frac{7}{8}$ incn. This distance must be increased $\frac{9}{16}$ inch, making a setting of $1\frac{7}{16}$ inch, to locate the center *p*, Fig. 42. The punch plate is next

doweled to the die and both the punch plate and the die are placed on the face plate, with the die side against the face plate. The die and punch plate, as one thing, are then placed against the tip of the adjustable size block which has been placed against the screws *k*, Fig. 44, and the plate *j*. The work is now clamped to the face plate as before. The hole *g*, Fig. 42, together with its mate in the punch plate and the recess *r*, Fig. 45 (*a*), is now spotted, drilled, and bored at one setting, thus insuring the alinement of the holes in the punch plate and the die. The recess *q*, Fig. 46 (*a*), of the punch plate is also

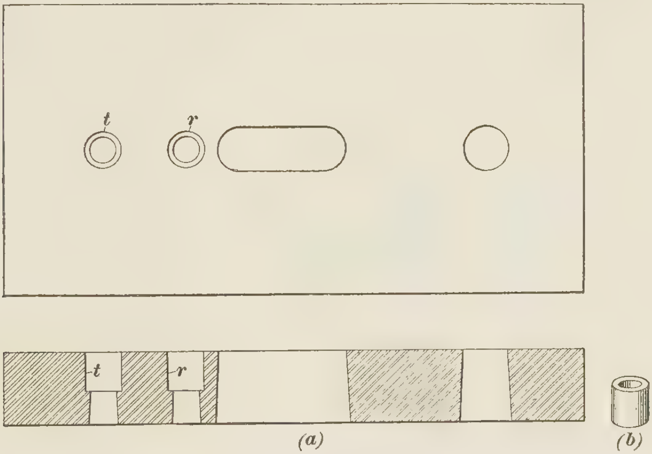


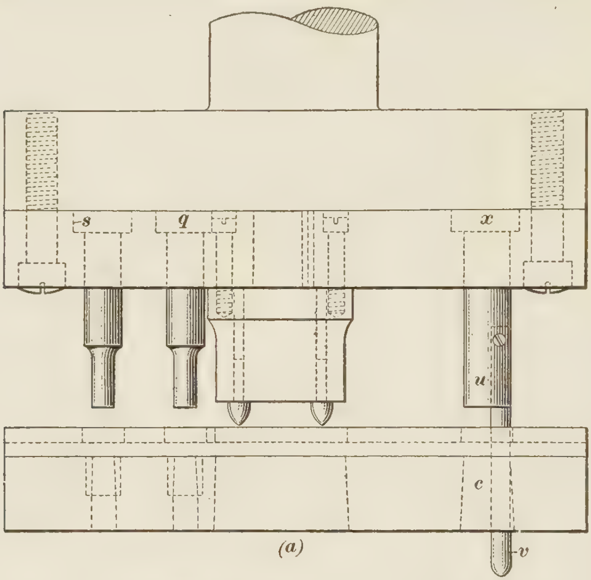
FIG. 45

bored at this setting. The recess *r*, Fig. 45 (*a*), is bored part way through to a diameter equal to that of the piercing punches. In a similar way, the hole *f*, Fig. 42, its mate in the punch plate, the recess *s*, Fig. 46 (*a*), and the recess *t*, Fig. 45 (*a*), are bored.

64. Die for Punching Web.—The hole *c*, Fig. 41, and its mate in the punch plate are bored at one setting. This hole is a die for cutting out the web shown at *d*, Fig. 40 (*b*). The punch *u*, Fig. 46 (*a*), which enters the hole *c*, carries a long stop-pin *v*, which never leaves the die. The strip is fed along until the web between the punched openings in the strip touches the stop-pin. As the punch descends the web is

punched out, and the strip may then be pulled along until the next web touches the stop-pin. The entire length of the strip may be fed through the die without a miss by pulling steadily on the stock and holding the treadle down. The stock leaves the die in two long strips as shown in (*b*).

65. Boring Web Die.—The center of the hole *c*, Fig. 41, is laid off on the center line *e*, a distance from the center *w*,



(*a*)


(*b*)

FIG. 46

which is $\frac{1}{4}$ inch from the right-hand end of *b*, of $\frac{1}{4}+\frac{1}{16}+1\frac{3}{8}+\frac{1}{32}=1\frac{23}{32}$ inches. The die and punch plate are then adjusted on the lathe face plate as before, and they are bored out to a $\frac{1}{2}$-inch diameter. The recess *x*, Fig. 46 (*a*), for the web punch is also bored at this setting of the punch plate.

66. Bushings for Piercing Dies.—The piercing dies are made by fitting hardened bushings, Fig. 45 (*b*), in the recesses

r and t, shown in (a). The bore of each bushing is made $\frac{1}{4}$ inch. The use of bushings here permits certain changes to be made in the size of the holes punched in the blanks. If the die were solid, considerable difficulty would be experienced in making a change. The bushings may be readily removed and other bushings having holes of a different size inserted. A tight press fit is ample to hold the bushing in place, the cutting stress being downwards. Should a piercing die be broken, repairs may be quickly made; whereas, if the die were solid, a complete new die would probably be required.

67. Finishing the Dies.—The web between the two holes bored in the blanking die is next filed to a line, after roughing

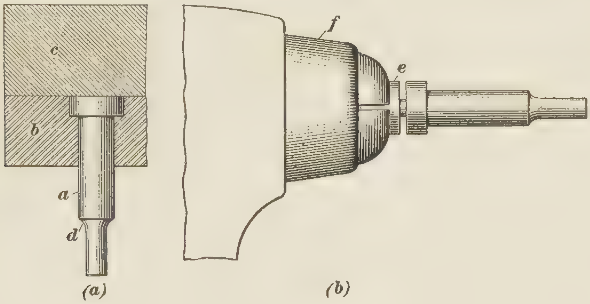


FIG. 47

out by broaching, milling, or chipping. The holes for the stripper are drilled and tapped, after which the die is hardened and ground. The die is now finished and ready for use.

68. Making Piercing Punches.—The piercing punches are made as shown in Fig. 47 (a), in which a is the punch, b the punch plate, and c the punch holder. The round corner d guards against cracks and provides stiffness. This punch may be made without centering, all the diameters being concentric, since they are all turned at one sitting, as illustrated in (b). The shoulder on the punch which fits in the recess of the punch plate prevents the punch from pulling out and the punch holder prevents the punch from pushing back. The punch stock e, Fig. 47 (b), is held in the spring chuck f of the bench lathe, just

enough stock being permitted to extend from the chuck to make the punch. The punch is now turned to size, the proper clearance being allowed between the punch and die, unless the punch is to be hardened and ground all over, the head excepted. In case the punch is to be hardened, enough stock is left on the punch to true up, by grinding, the warping caused by the hardening. As its head need not be hardened, the punch is left on the rod until it is hardened and ground; it is then severed with a cutting-off tool.

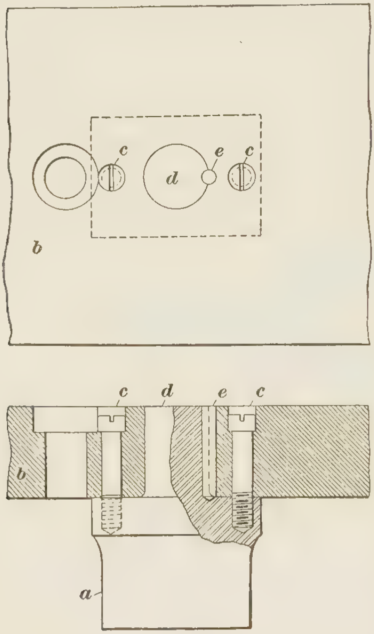


FIG. 48

69. Turning Blanking Punch.—The blanking punch is made as shown in Fig. 48, in which *a* is the punch, *b* the punch plate, *c* the screws for holding the punch to the punch plate, *d* the shank of the punch, and *e* a dowel-pin to prevent the punch from turning. Any spring to the punch will cause shearing; that is, the punch will be crowded over so that its cutting edge will strike the cutting edge of the die, dulling both. The large shank *d* will prevent shearing should a half cut be made; that is, when the strip has not been moved far enough to cover the entire die. The stock from which the punch is to be made is chucked in the lathe and the shank turned. The blanking punch should lack $\frac{1}{16}$ inch of entering the die as far as the piercing punches in order that they may be used as guides when fitting the blanking punch to the die.

70. Fitting Blanking Punch to Punch Plate.—To fit the blanking punch to the punch plate, the punch plate is laid on the die face and the approximate center of the blanking die

is laid out, after which the plate is clamped to the lathe face plate with this point central. A hole is then bored in it for a press fit of the shank of the punch. The seat for the punch is trued up at this setting to insure its being at right angles to the hole in the punch plate. The face of the punch is now blued and the punch is forced home in the punch plate, after which the hole for the dowel-pin *e*, Fig. 48, is drilled and reamed, the hole being so located that the pin will have a greater bearing in the punch plate, in order that it will remain in the punch plate when the punch is removed. The dowel-pin is next fitted and inserted, after which the piercing punches are placed in the punch plate.

71. Fitting Blanking Punch to Die.—To fit the blanking punch to the die, the piercing punches are entered in the

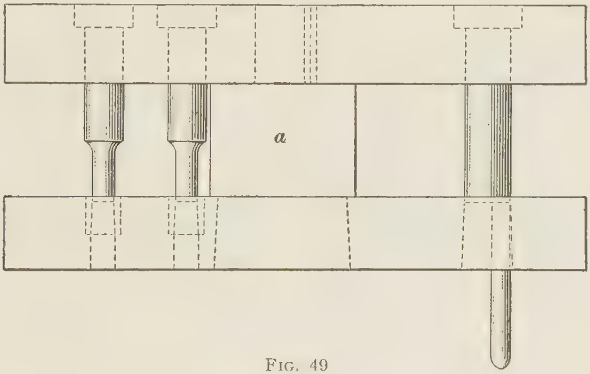


FIG. 49

piercing dies far enough for the blanking punch *a*, Fig. 49, to come in contact with the face of the die. The position of the blanking punch is thus located, after which the outline of the blanking die is carefully scribed on it. Before the punches are removed from the die, the outline traced is inspected to make sure that the scriber has followed the outline of the die closely. The punch is next removed from the punch plate and milled to the line scribed. The shank of the punch is started in the hole in the punch plate, being guided by the dowel *e*, Fig. 48. The punch is then forced home. When forcing the punch home, the half hole in the shank will follow the dowel and when finally

home the punch will be in the same position as when the line was scribed. The blanking punch, guided by the piercing punches, is forced in the die just far enough to show a clear line where the die has cut back the stock on the punch. The finishing, whether by milling or filing, may be done while the punch is in the plate, or the punch may be removed as often as desired

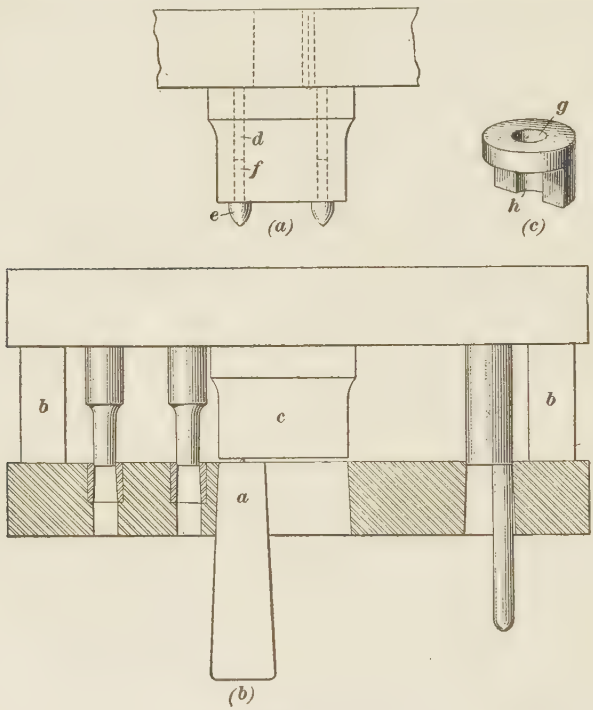


FIG. 50

with the assurance that it will line up with the die when returned. The punch is relieved as described in the making of plain blanking dies.

72. Locating of Blanking-Punch Pilots.—Any one of a number of methods may be used to locate the blanking-punch pilots so that the distance between the centers of the pilots, Fig. 50 (*a*), will be exactly the same as the distance between the two piercing punches. One way of doing this is

to locate the pilot holes carefully by the use of dividers. Another way of doing this is by the **center-punch method,** in which the pilots are located by the aid of a special center punch. When this method is used, a $\frac{1}{2}$-inch center punch *a*, in (*b*), is made with a shank of the same taper as the die. The piercing punches are next entered in the die as shown in (*b*) and the parallel strips *b* are placed between the punch plate and the die so that the blanking punch *c* will come within $\frac{1}{32}$ inch of the die. By holding the center punch against each end of the die, the centers for the pilots may be marked on the punch. The holes *d*, Fig. 50 (*a*), are now bored out on the lathe face plate and the pilots *e* are turned, making press fits between the shanks *f* and the holes *d*. This method cannot be depended on for closer accuracy than .002 or .003 inch.

73. The **jig method** may also be used to locate the blanking punch pilots. When this method is used, a sleeve is made as shown in Fig. 50 (*c*), the holes *g* and *h* being bored at the same setting. The radius of the large hole *h* is made equal to the radius of the end of the blanking punch. One-half of the sleeve is cut away for about half its depth as shown. This sleeve is used as a jig for drilling the holes *d*, in (*a*), the hole *h* being held against the punch while drilling. The drilling is done before the punch is relieved. This method, like the preceding one, is not to be depended on for extreme accuracy.

74. If, from the nature of the work, the pilots must be very correctly located, a method of great accuracy must be employed. Two methods that may be used when this degree of accuracy is required are the *adjustable-size-block method* and the *button method*. A number of days are often required to make the necessary special tools and only a few minutes to do the work. With either of these methods, the punch plate is first made in two pieces, one containing the piercing punches and the other the blanking punch. The piercing punches and the plate for the piercing punches are next made as previously described. The blanking punch and its plate and pilots are then made as described in one of the two following methods.

75. When the **adjustable-size-block method** is used to locate the blanking punch pilots, the shank of the punch is turned; the punch is doweled to the punch plate; and the punch and punch plate are then clamped to the face plate of the lathe, the adjustable size blocks shown in Fig. 43 (*a*) being used.

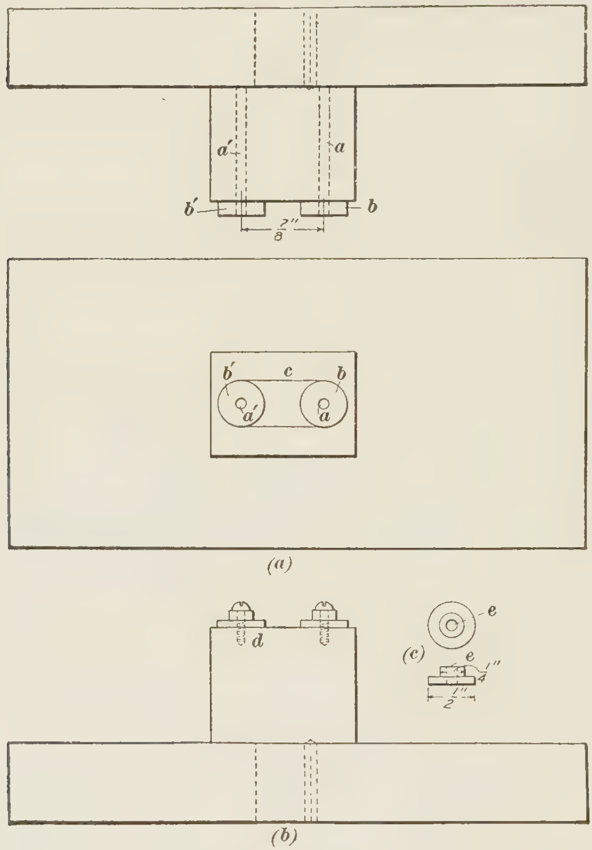


Fig. 51

The holes a, a', Fig. 51 (*a*), are next bored and the bosses b, b' are turned, a and b being finished at one setting and a' and b' at one setting. Referring to the drawing, Fig. 40 (*a*), it is seen that the diameter of the projections is $\frac{1}{2}$ inch and the center distance between the projections is $\frac{7}{8}$ inch. The punch is milled

to the lines *c*, Fig. 51 (*a*), the bosses *b* being used as a guide. When finishing the punch, it is forced into the die, the line obtained by the die cutting the stock on the punch being worked to. The punch plates are doweled to the punch holder when all the punches are in the die. The punch is now relieved and the pilots made as before.

76. When the **button method** is used to locate the blanking punch pilots, the shank of the punch is turned and the punch is doweled to the punch plate as before. The punch is then carefully laid out to obtain prick-punch marks for the centers of the holes *d*, Fig. 51 (*b*), approximately $\frac{7}{8}$ inch apart. A small hole is drilled and tapped at each prick-punch mark, after which two buttons are made as shown in (*c*), the hole *e* being made a trifle larger than the diameter of the screws to be used to fasten the buttons to the punch. The buttons are next fastened to the punch and adjusted until the measurement from button to button equals $\frac{7}{8}$ inch plus the radii of the outsides of the two buttons. A line is now scribed on the punch, the large diameter of the button being used as a jig, after which the punch and its plate is strapped to the lathe face plate and adjusted until one of the buttons runs true. The button is removed and the hole is trued up. The lathe is then set up to true up the other small hole. This small hole is then trued up and the pilots are made as before.

77. To test the accuracy of the holes bored, pins are wrung in the holes and the distance from pin to pin is measured with a micrometer caliper. This measurement should equal $\frac{7}{8}$ inch plus the radii of the two pins. The small diameter of the button need not be $\frac{1}{4}$ inch, this dimension being selected for convenience. The large diameter of the button need not be turned to exactly $\frac{1}{2}$ inch. In this case $\frac{1}{2}$-inch circles would be scribed on the punch with dividers, using the **V**-center point after the small screw holes were trued up. Lines would then be laid out tangent to the $\frac{1}{2}$-inch circles, and the punch finished to these lines.

DIES AND DIE MAKING

(PART 2)

DIE MAKING—(Continued)

CUTTING DIES—(Continued)

MAKING SUBPRESS CUTTING DIES

1. Selection of Subpress.—The most common type of subpress is illustrated in Fig. 1, and the square type of subpress, used for large work, in Fig. 2. More skill is required to make subpress dies than any other kind, the majority of cases requiring very accurate hand work. Let it be required to make a subpress die for making the plain washer shown in Fig. 3. A washer will be made complete, as with compound dies, at each stroke of the press. The subpress die is chosen, rather than a compound die, to secure greater accuracy. The simple washer is selected to assist in making clearer the principles involved. Let the subpress and dies be made as shown in Fig. 4, which is a sectional view of the type of subpress illustrated in Fig. 1. Details of Fig. 4 are illustrated in Figs. 5 and 6 and the letters representing the subdivisions in these two figures are the same as those used in Fig. 4.

2. Description of Subpress.—The base *a*, Fig. 4, is clamped to the bed or bolster plate of the press and is held to the frame or barrel *b* by the screws *r* and dowel-pins *s*. The plunger *d* has a vertical motion in the Babbitt bearing *c*, which

separates it from the frame. The plunger is connected to the ram of the press by means of the button *e*. The threaded cap *f* permits adjustment of the Babbitt bearing, thus compensating for wear. The blanking punch *n*, which is in the base, is held to the base by the screws *w*, and its stripper *q* is separated from the base by the springs *u*, which are held in place by the screws *v*. The piercing punch *j* is supported by its holder *k*, which, together with the blanking die *m*, is fastened to the plunger by the screws *t*. The die stripper *l* is forced downwards to the shoulder on the blanking die *m* by the spring *i*, the tension of which is adjustable by means of the spring screw *g*. The screw *x* serves to lock the spring screw after it has been set. During operation the stripper is forced upwards, compressing the spring by means of the stripper pins *o* and the collar of the spring pin *h*.

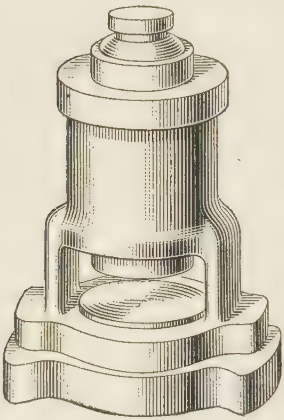


Fig. 1

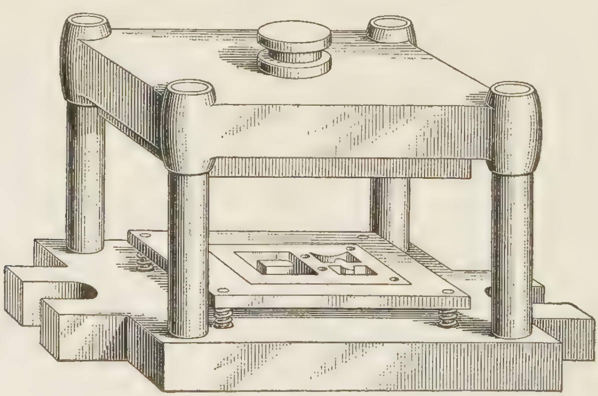


Fig. 2

3. Making Subpress Base and Frame.—To make the subpress base, the stock for the base, Fig. 5 (*a*), is gripped in the chuck by the part *a* and the bottom is faced, after which

the base is strapped to the lathe face plate. The outside of the part *a* is then turned, and the recess *b* is bored, thus insuring that the inside and outside of the flange will be concentric. The small end of the frame, Fig. 5 (*b*), is now gripped in the chuck, after which the bottom is faced and the hole *a* bored to fit snugly the part *a*, in (*a*), of the base. The frame is next removed from the chuck and attached to the face plate as shown in Fig. 7 (*a*). The frame *g* is attached to the fixture shown in perspective in (*b*), by the screws *f*. The shank *e* of this tool is tapered to fit the lathe spindle, and the part *d* fits the hole in the bore of the frame. The plate *a* is clamped to the face plate *b*, and the inside *c* of the frame is bored, a taper of two or three degrees being allowed, after which the outside of the frame is turned and threaded. The bore will now be fairly central with the part *a* on the base so that when the plunger is babbited the wall of Babbitt will be nearly uniform and the contraction of the Babbitt will be quite even. The splining tool, shown in Fig. 7 (*c*), being used, the four grooves *b*, Fig. 5 (*b*), are cut the entire length of the bore, the lathe being locked with the back gears, while cutting each groove. These grooves will prevent the Babbitt from turning. They must be parallel with the bore, for after they have been in use some time the wear is taken up by screwing down the cap; the taper hole in the frame causes the Babbitt to close on the plunger, thus restoring the fit.

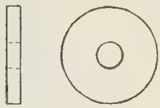


Fig. 3

4. Making Subpress Cap, Button, and Plunger.—The cap, Fig. 6 (*f*), is now bored and threaded to fit the threaded end of the frame, and bored to fit the plunger. The button, Fig. 6 (*e*), is turned up on centers, as it is necessary to use one of the centers when making the plunger. The plunger, Fig. 6 (*d*), which is made from solid stock, is next centered and rough turned, enough stock being left to true up. Using the face plate and steady rest as shown in Fig. 8, the inside of the plunger is drilled, bored, and threaded, the thread being fitted to the button. The button is then screwed into the plunger and the plunger and button are placed between the lathe

centers with the button end on the live center, the dog being placed on the button so that a cut may be taken the entire length of the plunger.

5. Each end of the plunger is measured carefully to make sure that it is being turned absolutely straight and it is turned

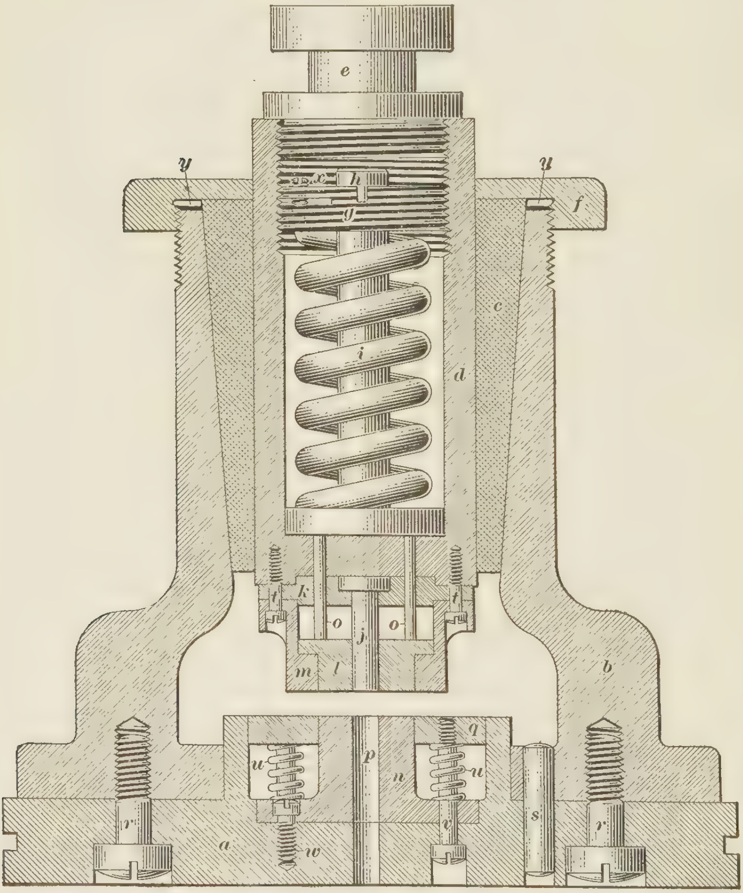


FIG. 4

to fit the hole in the cap *f*, Fig. 4. The final chip should be very light to avoid springing. The cut should be taken with a sharp

tool that will leave a smooth surface. A turned piece required to be straight should not be filed. The four grooves *a*, Fig. 6 (*d*),

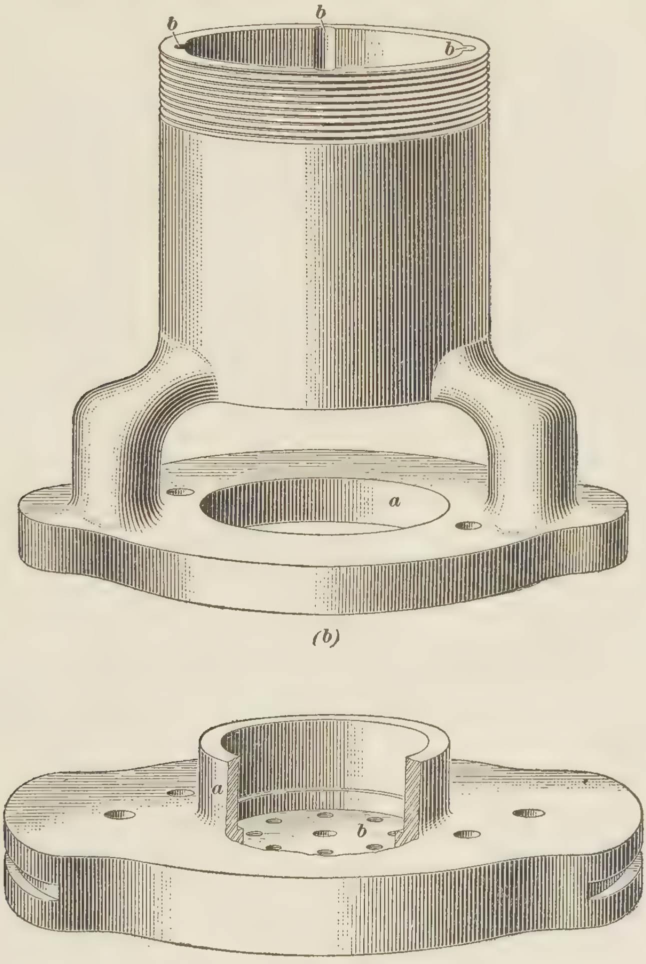


Fig. 5

are next cut, the spindle being locked by throwing in the back gears and a splining tool, as shown in Fig. 7 (*c*), being used. These grooves may be cut on a milling machine. They must be

parallel and smooth, for when the plunger travels up and down in the Babbitt the grooves act as guides to insure that the punch and die are in alinement. A ring is now made to fit the outside diameter of the recessed end of the plunger, having

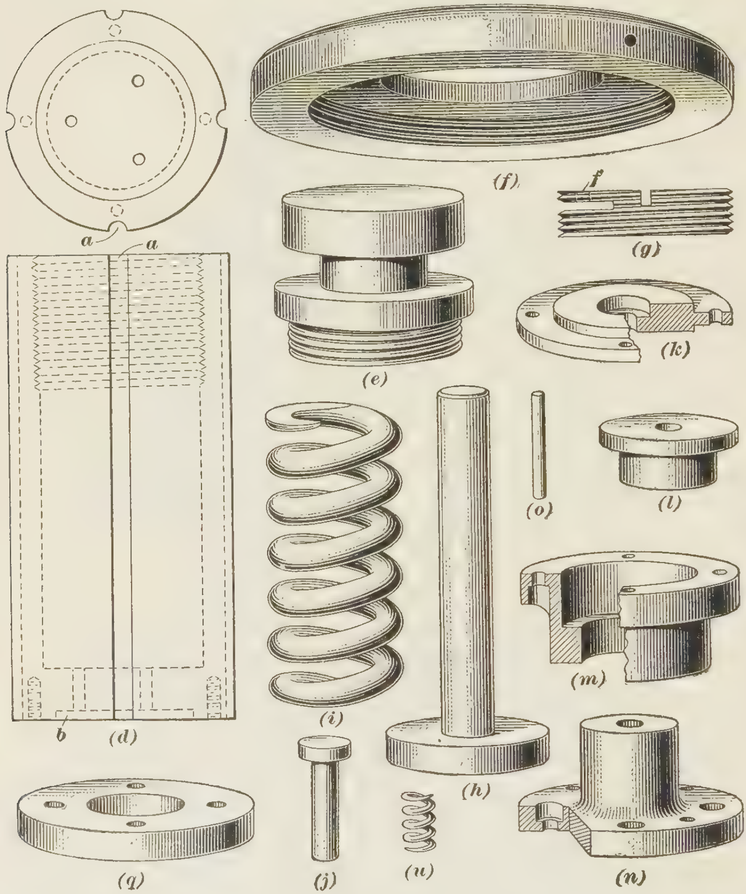


Fig. 6

its bore and outside diameters concentric. This ring is keyed to one of the grooves in the plunger. The button end of the plunger is placed on the live center and the ring is supported in the steady rest. The recess *b*, Fig. 6 (*d*), in which the

piercing-punch holder *k*, Fig. 4, fits, is now bored. The ring is used to prevent the steady rest from cutting ridges in the plunger.

6. Making Other Subpress Parts.—The punch holder, Fig. 6 (*k*), the die stripper (*l*), the blanking die (*m*), the blanking punch (*n*), and the piercing punch (*j*) should be made, as illustrated in Fig. 9 at *a*, *b*, *c*, *d*, and *e*, respectively, out of stock held in the lathe chuck, each piece being turned, drilled, bored, and cut off at one setting and due allowance being made for

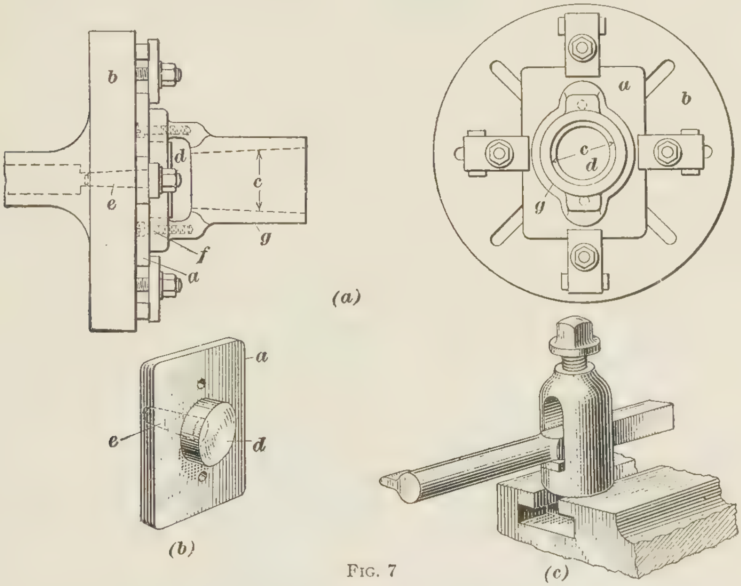


Fig. 7

grinding the hardened parts. The piercing punch, blanking punch, blanking die, and die stripper should be hardened and ground all over. The holes are ground first; or lapped, in case they should prove to be too small to be ground with the equipment at hand. The outside grinding is done by first gripping a piece of brass or soft steel in the grinder chuck, and grinding it to a wringing fit in the hole in the work. Without disturbing the ground rod, the piece to be ground is wrung on the rod, Fig. 10, and ground to size. By this method the hole and outside are sure to be concentric.

7. Babbitting and Finishing Subpress.—Before babbitting the subpress, it is necessary to rig up for the operation.

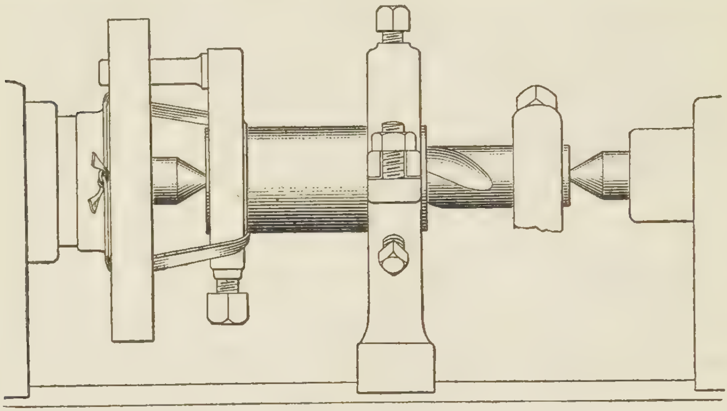


FIG. 8

To do this the blanking punch is secured in its seat in the base, after which the piercing punch is inserted in the punch holder, and the punch holder, together with the blanking die, is secured to the end of the plunger. The frame is next fastened to the base, the plunger is wiped with an oily rag and sprinkled with a

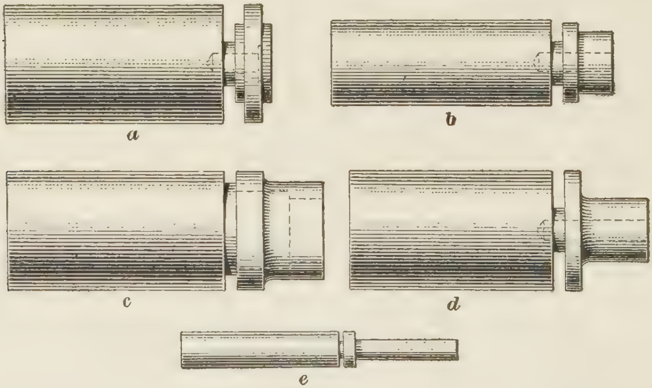


FIG. 9

thin coat of graphite as evenly as possible, the punch is entered in the die, and the cap is screwed on the end of the frame.

The hole in the cap fits the plunger, thus alining the plunger in the frame. The die is then inverted and placed on parallel strips *a* as shown in Fig. 11, after which the Babbitt is melted, the frame being heated at the same time just enough to prevent chilling of the Babbitt while pouring. When the Babbitt has attained a dark-red color, it is poured into the two openings in the sides of the frame and allowed to cool thoroughly without being disturbed.

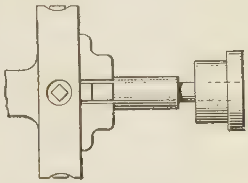


FIG. 10

8. The plunger is next removed and the base and frame are clamped to the lathe face plate, and a coarse-pitch, semicircular groove is then cut the entire length of the hole in the Babbitt. This groove is a channel for oil to lubricate the plunger. At this setting, the Babbitt which filled the annular space *y*, Fig. 4, is turned off. The frame is now removed from the base, and the springs, strippers, stripper pins, and tension screw are put in place, after which the faces of the punch and die are ground. After the faces are ground, the die is taken apart and the emery is cleaned from all the parts. The die is then reassembled and it is ready for use.

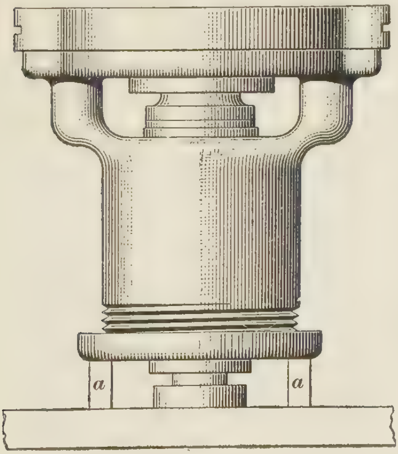
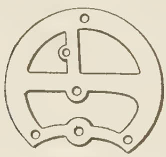


FIG. 11

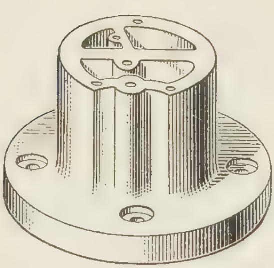
9. Proving Clearance in Subpress Dies.—The blanking punch is made perfectly straight, while a slight taper is provided in the piercing dies to permit the punchings to pass through. That the opening should have sufficient clearance to allow a free passage of the punchings is vitally necessary; but many dies are so small that this condition is difficult to determine. If dies with thin walls, as the one in Fig. 12 (*b*), were crowded by punchings they would burst. To determine whether the die has sufficient clearance, it should

be warmed, before it is hardened, and laid face down on a piece of paper that rests on a level surface. Melted Babbitt is then poured in the opening from the back. When cool, if the clearance is sufficient, the Babbitt will drop out freely. The high spots in the die will be indicated on the Babbitt. This test is repeated on dies having thin walls after they are hardened.

10. Irregularly Shaped Subpress Dies.—When subpress dies for irregularly shaped work, as that shown in Fig. 12 (*a*), are required, the punch is usually made first. The outline of the punch, Fig. 12 (*b*), is scribed on the stock and the surplus stock is removed by drilling, chipping, milling, filing, and scraping. On irregularly shaped work considerable hand work is necessary. After making the punch, it is used as a templet to lay out the die, and the die is worked out to shape in a way similar to that in which the punch was made. When transferring the outline of the punch to the die, the die is attached to the plunger and the punch is secured in its seat in the base. The plunger is then babbitted in the frame as described in Arts. **7** and **8**, and the outline of the punch is scribed on the die.



(*a*)



(*b*)

Fig. 12

11. Subpress Die for Small Gear.—Let it be required to make a subpress die for cutting the small gear blanks shown in Fig. 13 (*a*). The blanking die shown in (*d*) is turned up as before, the tooth forms being cut by means of the broach shown in (*b*). The pilot *a* of the broach is the same diameter as the bottom of the teeth of the blank, and the length of each step of the broach, from its cutting edge to the beginning of the next step, is a trifle shorter than the depth of the die, in order that each step on the broach shall enter the die before the next smaller step ceases cutting. The first step is made .002 inch larger in diameter than the pilot, and each succeeding step increases by .002 inch. Generally five

or six broaches are needed. The blanking punch shown in (*c*) and the broach are milled at the same setting of the machine. The splines *a* in (*c*) are cut to hold the ends *b* of the spider shown in (*g*). The spider is milled to shape, using a formed milling cutter, as illustrated in (*e*). When placed inside the blanking punch, as shown in (*f*), the dies for the spokes and the center of the gear are formed. The piercing punches for piercing between the spokes are fitted into the punch holder, which is similar to the punch holder shown in Fig. 6 (*k*).

12. The piercing punches are next made. To do this, the punch holder, made similar to the one shown in Fig. 6 (*k*), is attached to the end of the plunger and the plunger is lowered

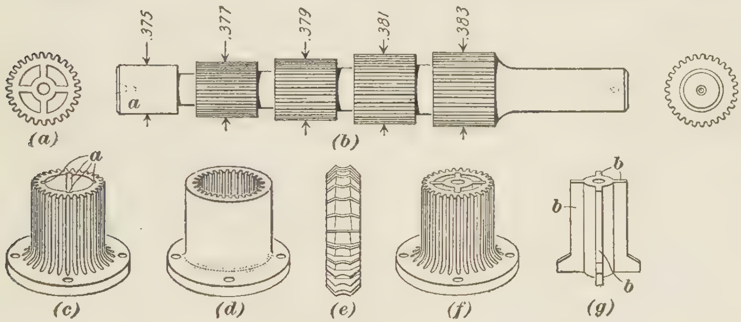


FIG. 13

until the punch holder touches the face of the punch. The center of the hole for the punch which pierces the bore of the gear is located with a prick punch that fits the hole in the spider of the blanking punch, which is used as a templet. The punch holder is then set up on the lathe face plate and this hole is drilled and bored.

13. The outline of the irregularly shaped openings in the blanking punch is scribed on the face of the punch holder to show the approximate location of the piercing punches. When the irregularly shaped openings are too small for scribing, the face of the punches is coated evenly with solder and the solder is forced in the piercing dies, which will cut their shape in the solder. The holes are then drilled and reamed approximately

in the center of the scribed outlines. Each piercing punch is made separately and forced into the punch holder. The punches are fitted to the dies while they are in the punch holder, which is attached to the plunger, the plunger being in place in the Babbitt bearing.

SHAPING DIES

FORMS OF SHAPING DIES

14. The operation of bending, pressing, or drawing a material to a given form, in a press or hammer, and by the use of dies, is known as **shaping.** All metals, when in such a state that they can be cut or punched, can also be shaped. The extent to which the shaping process can be carried depends on the ductility of the material. Some substances that are not metals, as paper, cloth, leather, hard fiber, wood, etc., can also be shaped; but some of these require special treatment, such as dampening or heating, to prepare them for the die work.

15. Shaping dies may be classified as follows: *bending dies*, *forming dies*, *embossing dies*, *drawing dies*, *curling dies*, *wiring dies*, *seaming dies*, *coining dies*, *extruding dies*, and *drop-forging dies*.

16. **Bending dies** are those which bend the work without distortion except the slight stretch on the outside and compression on the inside of the corners where the bending occurs.

17. **Forming dies** are those which form the work to a hollow shape by pushing it into a cavity in the die.

18. **Embossing dies** are those which shape the work by locally raising or lowering parts of the sheet from its original plane. The sheet does not change its thickness during the operation, there being a hollow on one side of the die to match every raised portion on the other side.

19. **Drawing dies** resemble forming dies, except that the outer portion of the sheet to be shaped is held under pressure

between two flat surfaces, from which it is drawn as the operation progresses.

20. Curling dies are those which bend the edges or ends of the work into a circular cross-section.

21. Wiring dies are those which curl the metal around a wire when the work requires stiffening.

22. Seaming dies are those which fasten two edges of the work together permanently by folding.

23. Coining dies are those which shape the work by applying pressure to the metal until it flows into the desired form.

24. Extruding dies are those which, by applying sufficient pressure to cause the metal to flow, make the thin cylindrical tubes of soft metal, which are used to hold paints, toilet pastes, etc.

25. Drop-forging dies are those used to distort the metal, by successive blows, while red or white hot, into desired shapes. These dies are described in another Section.

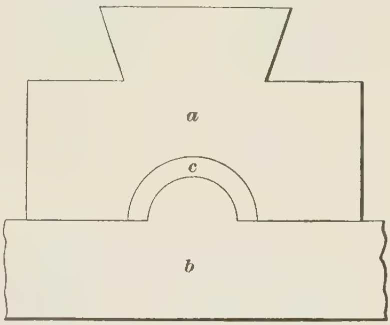


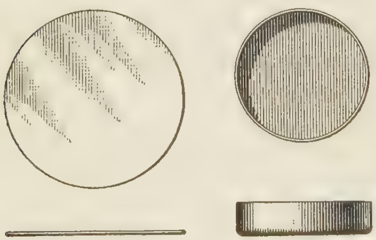
FIG. 14

26. Shape of Die Parts. When making any die for a shaping operation, it is to be observed that the lower and upper part cannot be of the same size. This fact is illustrated in Fig. 14, where a comparatively thick piece of material *c* is shown between the bending surfaces of the upper die *a* and the lower die *b*. Evidently, the upper die must have on its bending surface a curve of a radius equal to that of the lower die *increased by the thickness of the material.* Due attention must be paid to this fact when making any kind of a shaping die. It is also to be observed that any material will bend more easily around a curve than around a sharp corner, and at the same time there is less liability of forming a

crack at the exterior surface of the bend. For this reason, the corners of the bending surfaces should be rounded off. When the substance to be bent is thin and ductile, very little rounding off is needed; the harder and thicker the material, the more rounding must be given.

FORMING AND EMBOSSING DIES

27. Plain Forming Dies.—One of the simplest and most common examples of forming is illustrated in the changing of the flat circular blank, as shown in Fig. 15 (*a*), into a shallow cup, as shown in (*b*). This operation can readily be performed in an ordinary single-action press by the aid of forming dies. A single-action press is defined as one that has but one ram.



(*a*) (*b*)

FIG. 15

The forming dies may be constructed as illustrated in Fig. 16, in which a die shoe is shown at *a*, which is to be bolted to the bed of the press. The die, shown at *b*, is bored out to the outside diameter of the cup and polished on the inside, and fastened to the die shoe in some convenient manner, as by attaching it by means of a gauge ring and screws, as shown at *c*. This ring is bored out centrally to the size of the blank and its correct position in reference to the die is insured by fitting it to the cylindrical projection on *b*. The punch *d* is made equal in diameter to the inside diameter of the cup to be formed. The inside diameter of the cup equals the outside diameter less twice the thickness of the material. The blank is inserted in the gauge ring of the die, so that the punch as it descends bends up an outer zone of the blank and in passing through the die straightens out the wrinkles that form. The punch, with the work on its lower end, passes completely through the die. The upturned edges of the work spring slightly away from the punch, and as it ascends, the edges catch against the sharp lower edge of the die. The work

is thus stripped off the punch and falls through the opening in the bed of the press. The upper inner edge of the die must be rounded to a radius of about $\frac{1}{8}$ inch and highly polished. The die shown in Fig. 16 performs but one operation, which is the forming of the blank into the required shape.

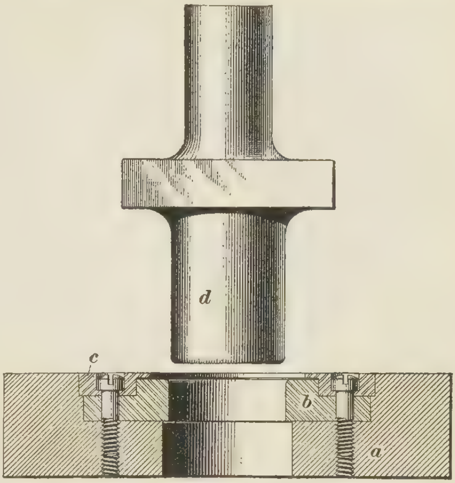


Fig. 16

28. Forming Dies with Tapered or Curved Sides.—Forming dies may also be used for forming shallow hollow articles with a flat bottom and tapering or curved sides, such as pie tins, and similar work. The lower die, which may be solid, is sometimes fitted with a spring-actuated ejector to push the work out of the die. This ejector would be required in case the shape of the work were such that it could not pass through, or be readily lifted from, the die.

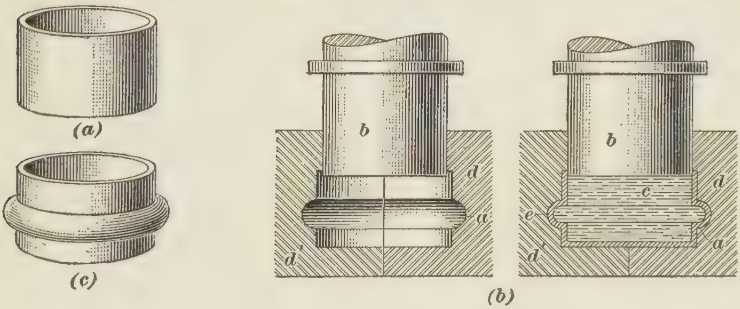


Fig. 17

29. Forming Dies in Two Parts.—Dies are sometimes made in halves in order that the finished piece may be removed. Fig. 17 (*a*) shows a cup to be formed in the dies shown in (*b*),

to the form shown in (*c*). One-half of the die *d*, in (*b*), is held rigidly; the other half, *d'*, is arranged to slide, being operated by a hand lever so constructed that the dies are locked together when ready for forming the work. The cup in (*a*) is filled with water, placed in the dies, and locked in position. The punch *b* presses on the water *c* in (*b*), forcing the cup into the recess *e* in the die. After the punch is withdrawn, the die is opened by means of the hand lever and the finished cup is removed. The die illustrated works best in a drop press, as the sudden blow does not allow the water to escape between the punch and die. For very thin work, soft rubber may be used instead of water.

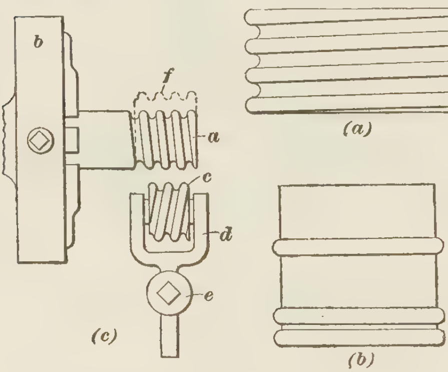


FIG. 18

30. Forming Dies for Beading. For forming threaded shells, illustrated in Fig. 18 (*a*), right- and left-hand threaded dies of the form shown in (*c*) are sometimes used. The inside roll or arbor *a* is held in the lathe chuck *b*; the outside roll *c* is held in bearings in the frame *d*, which is secured in the lathe tool post *e*. The work *f* is placed over the arbor *a* and the roll *c* brought in contact with it. As the chuck and work revolve the form of the rolls will be impressed on the work. The inside roll is smaller in diameter than the inside of the shell by an amount equal to the double depth of thread. The outside roll is the same diameter as the inside roll plus the thickness of the stock. Dies for forming the shell shown in (*b*) would be similar to the one shown in (*c*), but the grooves, in this case, would be square with the axes.

31. Embossing Dies.—Embossing dies are used chiefly for stamping letters and various ornamental designs. An example of work turned out by embossing dies is shown in Fig. 19.

In embossing dies there is a local stretching and compressing which depend on the form, depth, and width of the design. In many cases only the toughest metals will stand the depth of

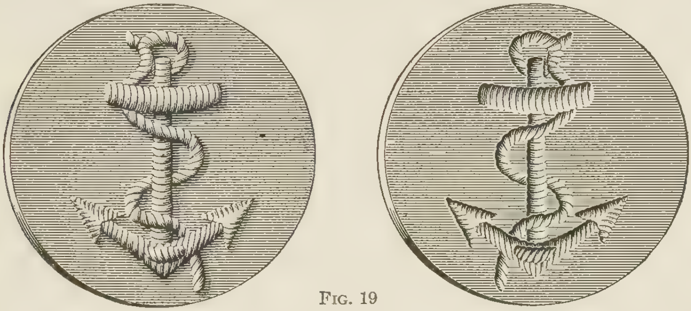


Fig. 19

relief necessary to get the proper effect. Sometimes ornamental designs must be toned down or made with less relief to prevent the tearing of the metal in certain spots or the undue wrinkling in other places. The working surfaces of embossing dies must follow the design of the raised pattern to be produced. Sometimes one surface is hard and the other soft. Many degrees of hardness or accuracy may be required, according to the material worked, the production demanded, and the artistic quality of the article produced.

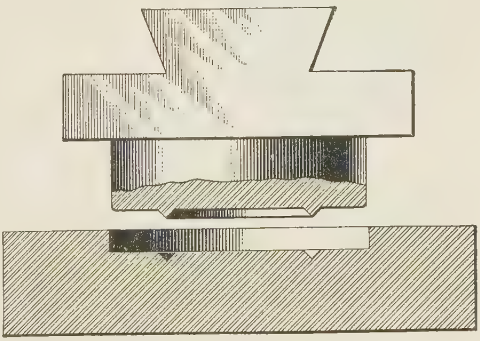


Fig. 20

A simple embossing die is shown in Fig. 20, where the raised outline of the work is cut into the lower die and the other is worked out to conform to the inside of the raised part of the work. This form of die, when for circular work, can be made on a lathe.

DRAWING DIES

32. The **drawing** operation is an extension of the forming process, differing chiefly in that, in the drawing process, the outer portion of the flat blank to be formed into a hollow shape is held tightly between two flat surfaces in such a manner that, as the blank is drawn radially inwards from between them, no wrinkles can form. Plain forming requires single-action dies and, as will be seen later, plain drawing requires double-action dies.

The products of drawing dies are a variety of cuplike forms, generally of cylindrical, conical, and approximately hemispherical shapes. Sometimes these forms have at the open end a flat, outwardly projecting flange; then the general shape may be termed hatlike.

33. Object of Drawing.—When an attempt is made to form a rather deep article from a blank in forming dies, the edges of the blank commence to wrinkle, and in extreme cases will even fold up so that the folds will lie over each other. These folds, as the wrinkles may be called, are shown in Fig. 21, which is an illustration of a tin-can cover that has been produced by the use of forming dies. For a short distance above the bottom, the sides of the rim are smooth. Farther up the wrinkles commence to form and gradually become larger toward the upper edge. When the blank is confined between two flat surfaces strongly pressed together by springs or other means and the metal is then drawn out from between them, no wrinkles will be formed. The drawing process is largely used for the cheap production of many articles, such as pots, kettles, dippers, and pans.

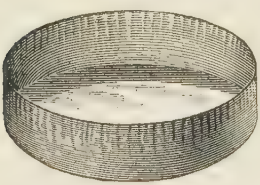


FIG. 21

34. Spring Drawing Dies.—The spring drawing dies shown in Fig. 22 are intended to draw the piece shown in Fig. 15 (*b*). This is an example of a double-action die for use on a single-action press. By comparing Figs. 16 and 22 it is seen

that the lower dies are identical. The part *a*, Fig. 22, that presses down on the blank to avoid wrinkles, is called the **blank holder**. The punch *e* is surrounded by the blank holder *a*, which is held to its lowest position by a stiff helical spring *b*. The punch is free to slide through the blank holder, when the latter comes to rest by reason of coming in contact with the blank lying in the gauge ring. To allow this sliding, the stem of the blank holder is slotted, as shown at *c*, and a cylindrical pin *d* in the side of the punch forms a stop for the blank holder. As the punch descends, the blank holder comes in contact with the blank and the spring is compressed before the punch strikes the blank; as it continues to descend, the part confined between the lower surface of the blank holder and the upper surface of the die is gradually drawn radially inwards, and, passing over the rounded upper edge of the die, is formed into a cylindrical rim without any wrinkles. The metal is compressed, or *upset*, circumferentially, while being stretched radially, its thickness remaining about the same.

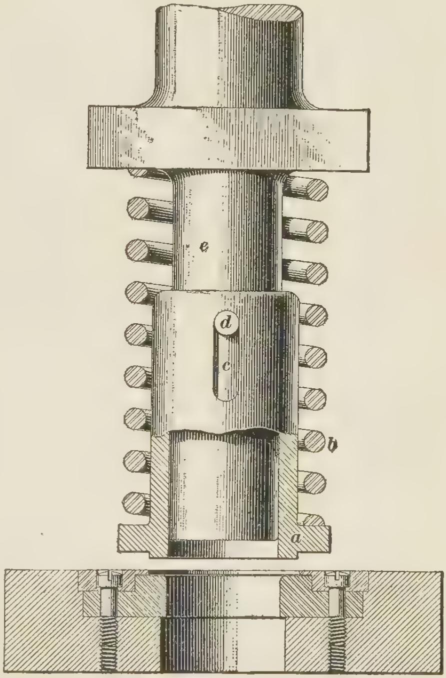
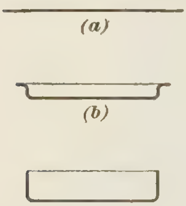


FIG. 22

The work appears in different stages in Fig. 23, where (*a*) shows a cross-section of the blank, (*b*) the cross-section when the punch has partly entered the die, and (*c*) the work when the punch is fully in the die. The work is stripped off the punch, as it moves up, by the sharp lower edge of the die.

If the rim formed by the drawing operation shows wrinkles, the pressure with which the outer part of the blank was held was insufficient. The remedy is to stiffen the spring or substitute a heavier one. On the other hand, if the punch tears through the blank, the spring is either too stiff or the die has sharp corners. In the former case, ease the spring or use a weaker one; in the latter case, round off the sharp corners of the die.

It is essential to successful drawing that the working parts of the die be highly polished and that the material to be drawn be soft. The depth to which a cup can be drawn in one operation depends on the ductility of the material; with well-annealed copper, a depth equal to two-thirds the diameter is often obtained. Experiment alone can determine for each particular case what depth can be attained by one drawing operation. The depth relatively to the diameter depends much on the thickness, as well as the quality, of the material.


(a) (b) (c)
FIG. 23

35. Size of Blanks for Shallow or Medium-Deep Cylindrical Cups.—The process of determining the diameter of blank required for a drawn cup is called **finding the blank.**

Rule I.—*To find the diameter of the blank required for a drawn cup when a finished cup is at hand, cut a round blank from material of the same composition and thickness as the cup, so that its weight, determined by a finely adjusted balance, will be equal to the weight of the cup.*

Rule II.—*To find the diameter of blank required for a shallow or medium-deep drawn cylindrical cup, multiply the diameter of the cup by four times its depth and add to the product the square of the diameter of the cup. The diameter of the blank will be the square root of the sum.*

EXAMPLE.—Find the diameter of blank for a cup to be drawn 2 inches deep and 3 inches in diameter.

SOLUTION.—Apply rule II; thus,

$$\begin{array}{lr} \text{Multiplying, } 3 \times 4 \times 2 = & 24 \text{ sq. in.} \\ \text{Squaring, } 3 \times 3 = & 9 \text{ sq. in.} \\ \hline \text{Total} & 33 \text{ sq. in.} \end{array}$$

By extracting the square root, the required diameter of the blank is found to be approximately $5\frac{3}{4}$ inches. Ans.

Should a table of areas of circles be at hand the following rule may be used:

Rule III.—*To find the diameter of blank required for a shallow or medium-deep drawn cup, multiply the circumference of the cup by its depth and add to the product the area of the bottom of the cup. From a table of areas, find the diameter corresponding to this area. This will be the required diameter of the blank.*

EXAMPLE.—Find the diameter of blank for a cup 2 inches in diameter and $2\frac{1}{2}$ inches deep.

SOLUTION.—Applying the rule, circumference $= 3.1416 \times 2 = 6.2832$ in.

$$\begin{array}{rl} \text{Circumference} \times \text{depth} = 6.2832 \times 2.5 = & 15.708 \text{ sq. in.} \\ \text{Area of bottom} = 3.1416 \times 1^2 = & 3.1416 \text{ sq. in.} \\ \hline \text{Area of the blank} = & 18.8496 \text{ sq. in.} \end{array}$$

By referring to a table of areas, the required diameter of blank is found to be $4\frac{7}{8}$ inches, nearly. Ans.

36. Size of Blanks for Deep Cylindrical Cups.—Deep cups, when drawn, are invariably longer on one side than the other and as a rule are trimmed to the proper length. Determine the approximate diameter of the blank by one of the rules of the preceding articles. Make two blanks having the diameter thus found, and mark a 1 on both of them. Having made the drawing die, form one of the blanks, preserving its mate. Should the blank require alteration, make two more blanks, embodying the change indicated, mark a 2 on both of them, and form one of the blanks, preserving its mate. Continue this process until a blank is found that forms satisfactorily. Its mate is now used as a templet for making the blanking die. The drawing die must be made before the cutting die. This rule applies whether the blank is cut in a previous operation, or cut and drawn in a single operation, as is the case in combination cutting and drawing dies to be described later.

37. Size of Blanks for Non-Cylindrical Cups.—For drawn or formed work that is not cylindrical, but circular, as for instance, that shown in Fig. 24, the following method may be used for obtaining the trial diameter of the blank:

Make a full-size drawing of the profile that is to be formed, as in Fig. 24. Commencing at the intersection of the axis with the profile, and to one side of the axis, step off divisions $\frac{1}{8}$ inch long, as *1*, *2*, *3*, *4*, etc. From the center of each division thus stepped off measure the perpendicular distance, as r_1, r_2,

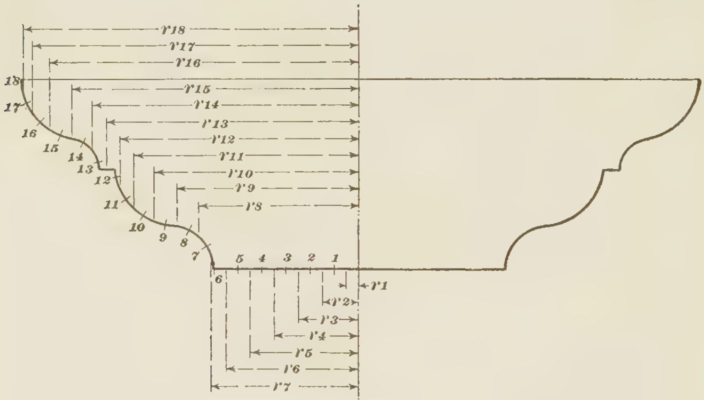


FIG. 24

r_3, r_4, etc., to the axis in inches. Extract the square root of the sum of these measurements to obtain the approximate diameter of the blank.

EXAMPLE.—Assuming that Fig. 24 is a full-size profile of the work, what would be the trial diameter of the blank?

SOLUTION.—Measuring the distances with a decimal scale, they are found to measure .06, .19, .31, .44, .56, .69, .75, .84, .95, 1.06, 1.17, 1.24, 1.31, 1.38, 1.48, 1.61, 1.70, 1.74 in. Their sum is 17.48, and the square root of this number is 4.18, which is the approximate diameter of the blank in inches. Ans.

Proceed as directed in the preceding article to obtain the templet for the cutting die.

38. Redrawing Process.—The process of redrawing is an extension of the drawing process; in other words, it is simply the

drawing process repeated in order to deepen the hollow shape formed by drawing. In redrawing, the diameter is reduced at the same time that the length is increased; or the diameter is not changed, the cup being drawn deeper by reducing the thickness of the walls. In general, no blank holder is required for redrawing dies and the work is usually done on a single-action press.

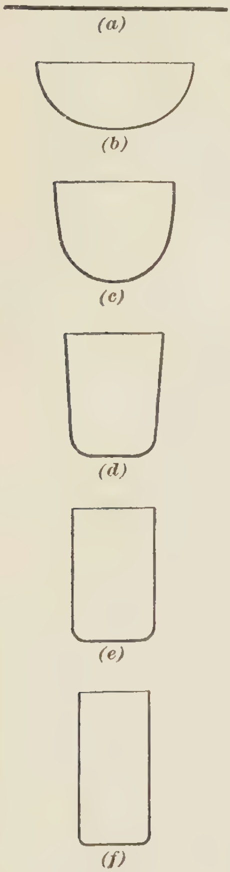


FIG. 25

39. Redrawing Dies.—Redrawing dies do not differ essentially from ordinary first-operation drawing dies. The cup is set in a recess, called the gauge ring, or gauge seat, and the drawing punch forces the cup through the die. The appearance of the cup in successive stages of the drawing and redrawing process is shown in Fig. 25. In (*a*) the blank is shown, which is formed into the cup shown in (*b*) by plain drawing dies or combined cutting and drawing dies. The cup is then placed into the gauge ring of the redrawing dies and the punch in descending forces the cup into the die, first into the shape shown in (*c*) and finally into that of an elongated cup shown in (*d*). This cup may be redrawn again, its appearance

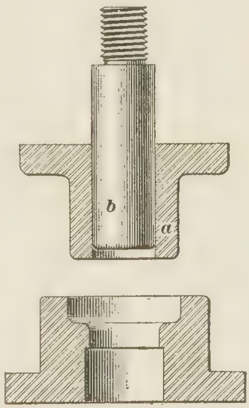


FIG. 26

when partly redrawn being shown in (*e*), and when fully redrawn in (*f*). The greatest amount that the diameter of a cup can be reduced in each drawing operation is usually placed at two-fifths of the diameter. Thus, a cup 2 inches in diameter may in one drawing be reduced to $2-2\times\frac{2}{5}=1\frac{1}{5}$ inches. Experiment

alone will determine positively for each particular case if this reduction of diameter can be obtained. The amount depends on the character of the metal and the thickness of the sheet. In Fig. 26 is shown, in a vertical section, a pair of double-action redrawing dies in their simplest form, *a* being the blank holder and *b* the punch. These dies are suitable for drawing (*d*) into (*f*) as shown in Fig. 25. Double-action redrawing dies are not often used.

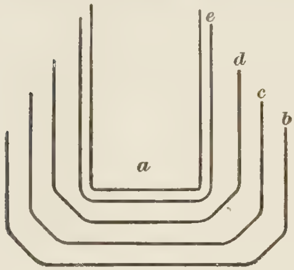


Fig. 27

Single-action redrawing dies are those used for a slight redrawing, the use of a blank holder not being required. They are forming dies employed to redraw the work. In Fig. 27 are shown in vertical section five stages of drawing a deep cup *a*. The piece at the end of the first operation is shown at *b*, and *c*, *d*, and *e* show successive operations. The finished cup is shown at *a*. The fifth operation, being a small reduction, is performed by single-action redrawing dies.

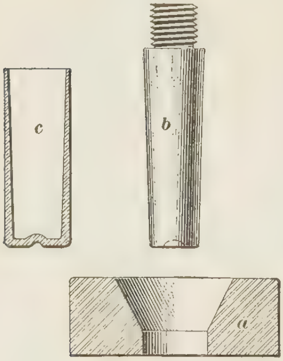


Fig. 28

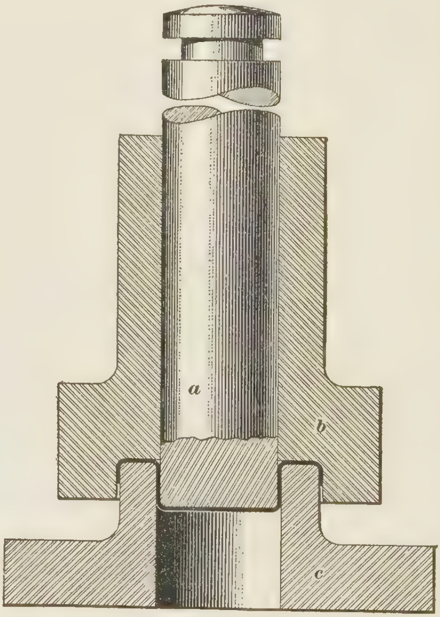


Fig. 29

A single-action redrawing die is shown in Fig. 28. The operation consists of squeezing thinner the walls of the cartridge shell *c*, by making the space between the punch *b* and the die *a* smaller than the thickness of the cup to be redrawn. In this case the punch is conical and the walls of the shell thinner at the top end. The die is enlarged at the top so that the cup may be readily located in it.

40. Reverse Redrawing.—The redrawing of a cup in the reverse direction is known as reverse redrawing. Fig. 29 shows dies for reverse redrawing designed for a double-action press. The figure shows between the punch and die, a cup that is partly redrawn; it will be observed that this cup is being redrawn in a direction the reverse from that in which it was

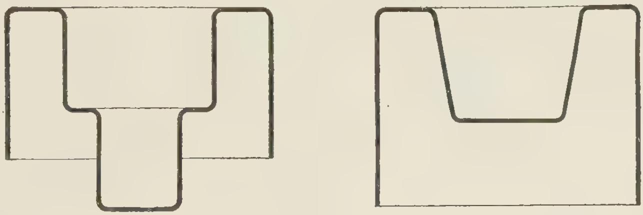


FIG. 30

drawn. In the illustration, *a* is the punch, *b* the blank holder bored to fit the outside of the cup, and *c* is the die, the outside of which is turned and polished to fit nicely the inside of the cup. Shapes that may be redrawn by reverse redrawing are shown in Fig. 30 and will serve to suggest others.

CURLING, WIRING, AND SEAMING DIES

41. Curling.—The curling process is one in which the end of a hollow object is bent either outwards or inwards into an approximate circle, thus forming a hollow ring at the end of the object. The general form of the curling die for a ring of circular cross-section is shown in Fig. 31. The die may have an inside or an outside curl, according to the requirements of the case.

42. Plain Curling Dies.—A form of curling dies, shown in Fig. 31, is intended to curl a rim *a*, Fig. 32, around the edge of the work. Referring to Fig. 31, the upper die *a* has a projection that fits the inside of the work, and a semicircular groove in its face at the base of the projection, as shown at *b*. The upper end of the lower die *c* is recessed to receive the rim, and the inclined surface of the recess assists in rolling it inwards. This design is shown to a larger scale in Fig. 32, where the rim is fully formed. The diameter of the curl, or rim, that can be produced is rarely over $\frac{3}{16}$ inch for a good quality of tin plate; if a larger rim is formed, the metal will be stretched so much that it will be torn. If it is well annealed and has not been hardened by any previous drawing, forming, or embossing operation, a larger rim can sometimes be curled. When the work is of such shape that it cannot readily be removed with the fingers from the lower die, an ejector, as *d*, Fig. 31, may be used to advantage.

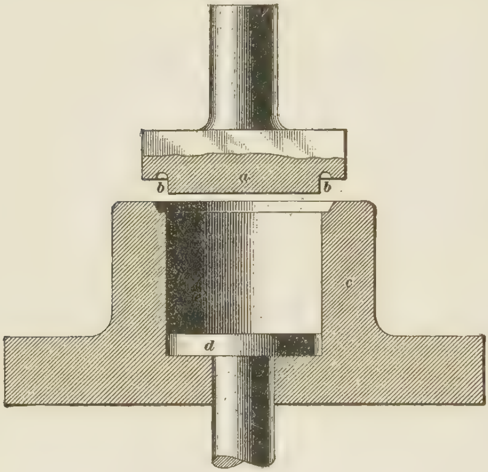


FIG. 31

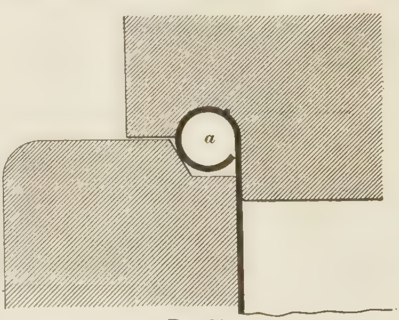
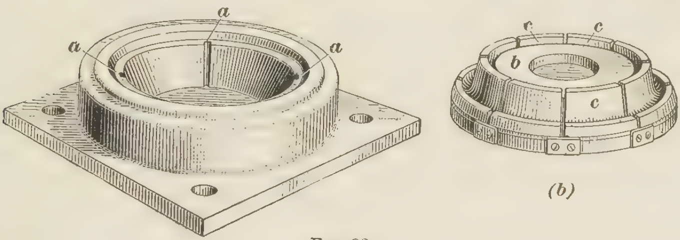


FIG. 32

43. Tapering Curling Dies.—The tapering curling die shown in Fig. 33 is arranged for curling the top of a rather deep dish pan. The die, shown in (*a*), is of cast iron and fits

the outside of the pan, grooves being provided at *a* to receive the seams of the pan, which is pieced rather than drawn. The punch is shown upside down in (*b*). It is usually made of an iron body *b* to which are attached steel sections *c*, which form the grooved working surface that does the curling. In this case the working surface is divided into several movable sections held outwards by springs. In operation, these sections are pushed inwards, forming a groove of smaller diameter, as the punch descends into the conical pan. For conical work that is smallest at the top, like coffee pots, etc., this action is reversed, and the sections, which are in contact with the work at the outset, expand as the punch goes down. In both cases, the return of the ring to its normal size is caused by a number of spiral springs set in the body of the punch. For parallel-sided



(*a*) (*b*)

Fig. 33

work, the curling ring is solid. An example of a solid curling ring is shown in Fig. 31, the work being a tin cup or a dinner pail.

When curled work is of much depth, the lower part of the die is made to swing or slide forwards for inserting and removing the work, thus avoiding the necessity of a very long stroke in the press ram, or the dies are made in halves, which are separated by being slid apart.

44. Wiring.—The operation of putting a wire in the curl is known as wiring. Greater stiffness is thus given to the top edge of the object. The work may be cylindrical or conical, and may have the large end either at the bottom or the top. The object need not be circular, but may be elliptical or have flat sides with rounded corners. The same die may be used for both wiring and curling operations.

False wiring is a term known to the tinware trade meaning wiring with the wire left out, and is the same as curling. The term is seldom used, however, in describing goods, which are supposed to be wired in any case, but oftentimes are of such design as to be thought good enough with an empty curl.

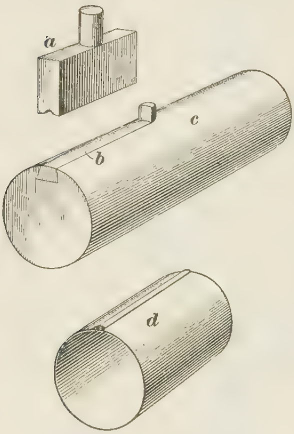


FIG. 34

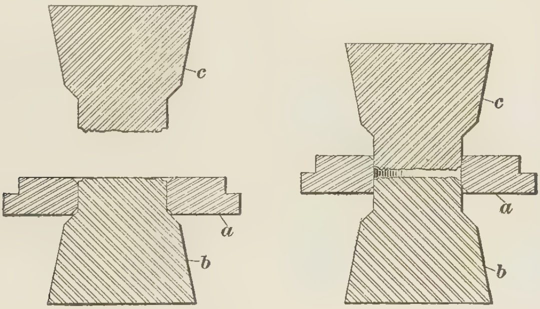
45. Seaming Dies.—Seaming dies are made to press against the inside and outside of a can, a bucket, a pan, a stove-pipe, etc., where the edges are folded together to make a joint. They finish the joint by squeezing the folds together closely. The die usually has a smooth face and the punch a grooved face fitting the projecting seam. A punch and die for an outside seam on a can body are shown in Fig. 34; *a* is the punch, and *b* the die mounted on the horn *c*, which may be inserted in a press of proper form. A sample of the work is shown at *d*. If the seam is to project inside the work, the upper part must have a smooth, concave face and the lower part must be grooved.

COINING AND EXTRUDING DIES

46. Coining Process.—The operation of pressing material so that it flows into the spaces of the dies, is known as **coining**. Brittle materials cannot be so treated to any great extent, although some substances apparently non-ductile flow in a remarkable way. The ductile metals and some other substances, such as clay, wax, butter, etc., may be used in the coining process. Such ductile metals as steel, iron, copper, etc. will flow farther and under very much less pressure if heated red hot than if cold. In the coining process these flowing materials are usually confined in dies or molds to bring them to the desired shape.

47. In the coining of money, medals, and badges of various sorts, the metal is worked cold. The impressions on the sides of the coin are made by dies engraved with the proper design, working in a collar. The collar confines the metal, and prevents it from spreading too far edgewise, and also serves as a mold for the edges. These edges may be smooth, as in American cents, or *reeded* with small grooves, as in American silver coins of various sizes.

In order to give a thickened rim, and to insure the rounded corners that are desirable, the disk of metal from which a coin is to be made is first made into a *planchet*. This process, called *milling*, consists in rolling the coin between grooved jaws so as to form a thickened and well-rounded rim. The pressure of



(a) FIG. 35 (b)

the dies causes the metal to flow into and fill all the spaces that form the inscriptions and ornamental or emblematical designs, and also forces the metal out sidewise to fill the collar and form any reeding or lettering that may be cut on the rim. Were the pressure too great, the metal would flow up into the small apertures between the dies and collar, forming a thin fin projecting at right angles to the face of the coin. The action of the dies must therefore be limited, so as to stop before this thin fin commences to form. Coining differs from embossing in that in coining the metal flows, whereas in embossing the metal does not change in thickness.

48. Coining Dies.—In the pair of coining dies illustrated in Fig. 35, the collar *a* surrounding the lower die *b* is fastened to

the bed of the press. In (*a*) is shown a section of the collar and dies when the upper die *c* has ascended its full distance and the lower die has risen into the collar to eject the finished coin and allow it to be removed by the fingers in case of hand feeding, or swept off by the next incoming planchet if the press is automatic. In (*b*) are shown the same dies when in closed position at the time the impression is being made. The space between them represents the exact size and shape of the coin, except that the corners may be rounded after coining.

Such dies may be made for coins of other than circular contour, as elliptical, octagonal, etc.

49. Extruding Dies.—The **extruding process,** also called *tube squirting*, is analogous to coining, as the metals are worked cold. It consists of pressing small disks of soft metal, such as lead, tin, and various alloys, into such thin cylindrical tubes as are used for holding paints, pastes, etc. In Fig. 36 (*a*) is shown a pair of dies for this purpose. In (*b*) is illustrated a punched disk of metal and in (*c*) is shown the tube after the pressure has caused the metal to follow the shape of the lower die, including the hole in the center and the threaded neck. The pressure of the punch causes the surplus metal to flow up the sides of the punch in the form of a thin shell, the length being determined by the amount of squeezing after it commences to crowd upwards. Where the work has a thread coined on it, it must be removed from the die by rotation to unscrew it.

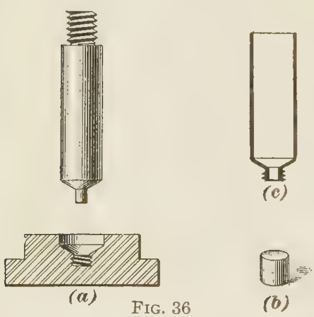


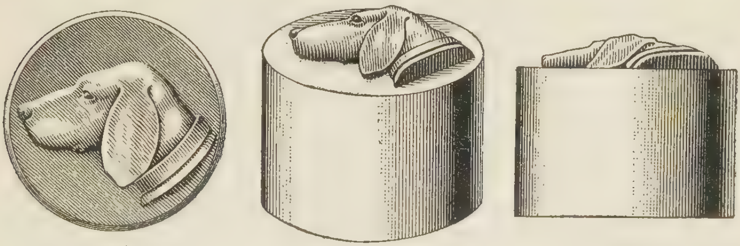
Fig. 36

50. If the lower die has a cylindrical recess and the punch is a plain solid cylinder, the tube would of course be a plain shell with a flat bottom, the thickness of the latter depending on the distance the punch descended, and the thickness of the walls on the amount of space between the punch and the die. In such a case the blank in (*b*) might be thinner than that shown and of larger diameter.

MAKING EMBOSSING DIES

51. In order to make the embossing die for producing the button shown in Fig. 37 (*a*), the workman must be an artist as well as a skilled mechanic. Embossing dies may be made by either the hob method or the die-sinking method, or by a combination of the two methods.

52. Hob Method.—Let it be required to construct a punch and die for making the button shown in Fig. 37 (*a*). To do this, a hob is first made. A **hob** is a tool having a raised design on its face, used for making an embossing die. The hob shown in (*b*) is made of tool steel. The face of the steel is blued and the outline of the design is laid out on it. The stock is cut away, leaving only the outline, as shown in (*c*), raised on the surface.



(*a*) (*b*) (*c*)

FIG. 37

With hammer, cold chisels, gravers, scrapers, and files the edges and design are rounded into shape, after which the hob is hardened. By hydraulic pressure or by a drop hammer, the hob is forced into the annealed-steel die block, most of the stock being first removed so the hob will be used to displace a small amount of metal only. The die is then polished and hardened.

53. The upper part or punch is called the **force,** and is made by pointing a piece of tool steel to approximately the same size as the design, heating it to a bright red, securing it to the hammer of a drop press—that is, a press in which a heavy hammer operates between vertical guides either by steam or by its own weight—and driving it into the design in the die, which has previously been set in the bed of the press. After

the force has cooled it will be found to have shrunk considerably and to be covered with scale. This is desirable, for, as explained in Art. **26,** the force or punch in this case should be smaller than the die. The scale is removed, the force is smoothed on its face, and the die and force are tested, a piece of some soft metal such as copper being used to make sure that the metal will be driven into the entire space between the die and force. The force is then hardened. For embossing very thin work, such as candy tongs, the punch may be a plain piece of steel faced with spring rubber. The steel is formed with a metal wall that surrounds the rubber to restrict its movement.

54. Die-Sinking Method of Making Embossing Dies. If the design is plain or high pressure is not to be had, the die may be sunk by chipping or milling it to shape and finishing it with gravers and files. The die-sinking method depends on the skill of the workman, which is developed by experience. When sinking a die, the reverse of the design is cut in the stock and to test the form wax is pressed into the depression. When removed the wax will show the reverse of the die, or the desired design.

55. Combination Method of Making Embossing Dies. The die may be made also by combining the hob and the die-sinking methods. A hob is comparatively easy to make, as the design stands out. The die is chipped or machined nearly to its finished shape and then finished by driving the hob into it with a drop hammer, a hand hammer, or a power press.

COMBINATION DIES

FORMS OF COMBINATION DIES

56. Combination dies may be classified as *plain combination dies*, *gang combination dies*, and *progressive combination dies*.

Plain combination dies are those, which cut and shape work in one complete piece at each stroke of the press.

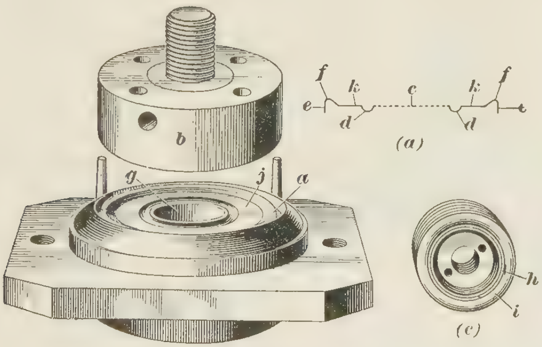
Gang combination dies consist of two or more plain combination dies grouped together, by whose use, at each stroke of

the press are made the same number of complete pieces as there are dies.

Progressive combination dies are those which combine cutting and shaping, so that while one part of the die is doing a cutting operation another part is doing a shaping operation on the piece that was blanked at the previous stroke. Two operations are performed at each stroke, but on different pieces of work. Hence, a piece is finished at each stroke of the press.

PLAIN COMBINATION DIES

57. Cutting and Forming Combination Dies.—A cutting and forming die for making the tops of fruit cans, the outline of which is shown in Fig. 38 (*a*), is illustrated in (*b*).



(*b*) FIG. 38

The bottoms of the cans are just like the tops, except that the hole *c* and the beading *d* are omitted. For can tops, a piercing punch for punching the holes *c* is located at the center of the large punch *b*. The piercing punch then makes the hole *c*, forcing the waste stock through the opening *g* in the die. The outer edge of the punch *b* shears or punches the outer edge of the can top, the shearing taking place between the edges of the punch *b* and the portion *a* of the die. The lower face of the punch *b* is so formed that it serves as a forming die to turn down the edge *e*, raise the ridge *f*, and form the depression *d* in the can top. The portion for forming the depression *d* is placed

on the same piece that carries the punch for punching the hole *c*, and this piece is arranged to screw into the center of the die. The loose piece is shown in (*c*), the cutting edge that cuts out the hole *c* in the top being illustrated at *h*, and the ridge that forms the depression *d* being shown at *i*. The cutting edge *h*, of course, projects out farther than the ridge *i*. The flat surface *j*, Fig. 38 (*b*), corresponds to the flat surface *k* in (*a*) in the top of the can. When it is desired to punch can bottoms, the piece shown in (*c*) is unscrewed from the punch *b*, and the centers of the can bottoms will remain flat.

58. In order to form the small caps that cover the opening *c*, Fig. 38 (*a*), a punch of the form shown in Fig. 39 is frequently used. The cross-section of the cap is shown in Fig. 39 (*a*). The hole in the center serves as a vent when the can is being sealed. The blanking is done by using the blanking punch *b* and the blanking die *d*, illustrated in (*b*); the piercing is done by the piercing die *e* and the piercing punch located in the center of *b*; and the forming is done by the punch *b* and the die *c*. The die *c* is supported by springs, that permit the die to descend part way in contact with the stock, the finished cap being ejected by the action of the springs when the punch is raised.

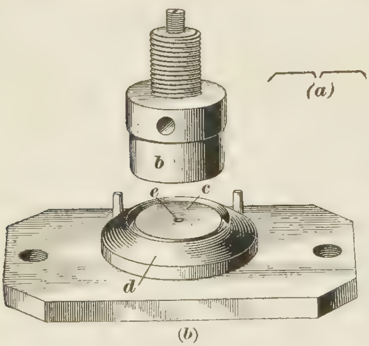


FIG. 39

59. These two sets of punches and dies are illustrated to show some of the classes of work that can be made with this style of tool. Many pieces of metal of complicated form can be made by combination punches and dies by properly arranging the cutting and forming portions of the dies. The solution of any problem of this kind is simply an application of the principles illustrated in the different cases shown to the problem in hand. It is possible to combine the different parts in an almost endless variety of ways.

60. Cutting and Embossing Combination Dies. Dies may readily be made to cut the blank and do the embossing in one operation. The punch should have no projections extending downwards beyond its cutting edge. If there are such projections, they will strike the blank, and draw it out of shape before it is cut. An ejector must usually be fitted to a combined cutting and embossing die. This ejector may be spring-actuated, or be positively operated by some moving part of the press, as is most convenient.

61. Cutting and Drawing Combination Dies.—Cutting and drawing combination dies may be subdivided into *spring-actuated*, and *double-action* combination dies.

Spring-actuated cutting and drawing combination dies are those which operate on a single-action press, the blank holder being actuated by a spring.

Double-action cutting and drawing combination dies are those which operate on a double-action press, the punches and blank holder being moved by two separate rams.

62. When a large number of pieces are to be drawn, dies may be designed that will cut the blank and draw the cup at one stroke, thus greatly reducing the time per piece. A spring-actuated cutting and drawing combination die designed to cut and draw the piece shown in Fig. 15 (*b*), is illustrated in Fig. 40. In the figure, *a* is the die shoe that holds the blanking die *b*, which is bored to the diameter of the blank, with its upper edge sharp. The blank is cut out by the blanking punch *c*, the outer edge of which is also sharpened to form a cutting edge. The punch is bored centrally to the outside diameter of the cup and the inner edge is nicely rounded. An ejector *d*, actuated by the helical spring shown, serves to push the cup from the upper die in case it should stick there. This ejector is free to move in the direction of its axis, and is confined as to its lowest position by a shoulder in the cutting punch and an abutting flange of its own.

The blank holder *e* is placed within the lower die; it surrounds the drawing punch *f*, which is stationary in this case. The blank holder also serves to strip the finished cup from

the punch. The pressure on the blank holder is obtained from a helical spring placed below the die shoe; this spring operates on a movable sleeve *g* with a large flange in which pins *i* are carried. These pins are passed freely through holes in the die shoe and the flange of the punch; they abut against the lower surface of the blank holder, which is thus actuated by the spring. The lower die must be provided with a suitable guide strip and gauge pin for the stock, arranged in the same manner as for any ordinary cutting die. These appurtenances have been omitted from the drawing for the sake of clearness.

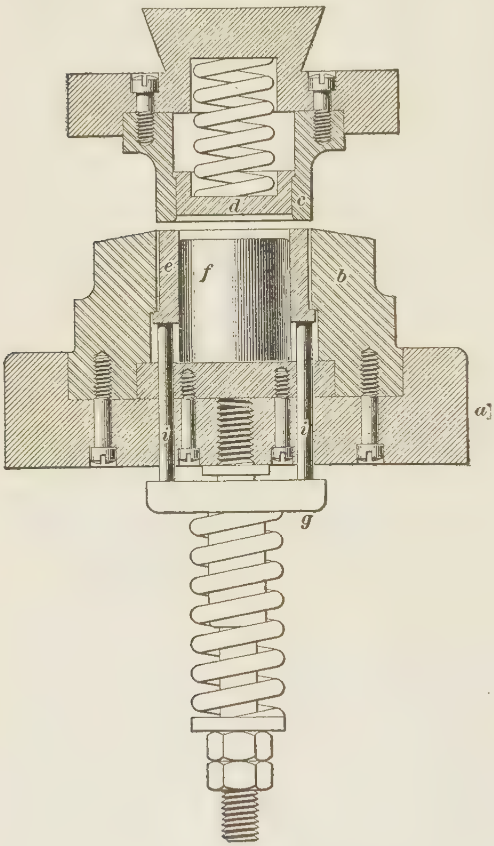


FIG. 40

63. The operation of these dies is as follows: The descending punch *c*, Fig. 40, cuts the blank from the stock; the stock is immediately gripped by the blank holder and confined between its upper surface and the lower surface of the cutting punch, the spring below the bolster giving the pressure necessary to prevent wrinkling during the drawing. As the punch keeps on descending, the blank and blank holder are carried down until the blank strikes the upper surface of the forming punch *f*; the outer

zone of the blank is then gradually pulled out and the cup is formed around the punch. The appearance of the work in successive stages is the same as was shown in Fig. 23, except that the work will be bottom side up.

In order that the blank holder may be inserted, the lower die *b* and drawing punch *f* must be made separate. They may then be connected in any convenient way that will insure proper centering. All spring-actuated drawing dies are intended to be used in single-action presses, although they are double-action dies.

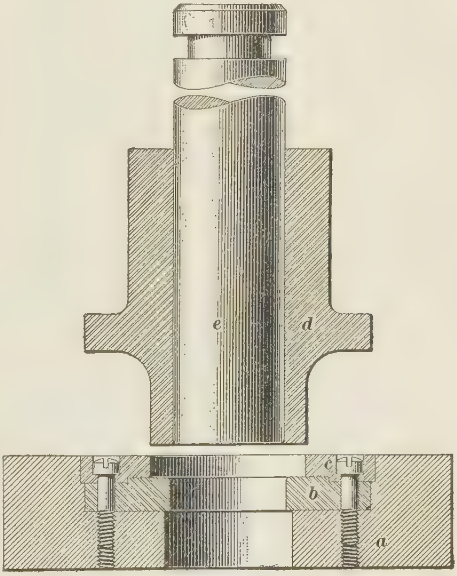


FIG. 41

64. When a double-action press is available, a very much simpler design of drawing die is possible. Such a press is provided with two rams working within each other, and independently adjustable. The outer ram, termed the ram, is so actuated that for a certain period of the revolution of the press shaft it will be at rest. The inner ram, termed the plunger, continues its downward motion, giving a certain excess travel, by which is measured the attainable depth of work. Fig. 41 shows a design of double-action press, cutting, and drawing combination dies intended to form the cup shown in Fig. 15 (*b*). In Fig. 41, *a* is a die shoe bored to receive the drawing die *b* and the cutting die *c*. To insure the correct location of the two dies with reference to each other, the one may be recessed to fit a central projecting shoulder of the other, as shown. The two dies may be rigidly held together by any convenient means.

65. The blanking punch *d*, Fig. 41, which is the blank holder and at the same time the cutting punch for the blank, is fitted to the ram, and the inner part, or drawing punch *e*, is fitted to the plunger. The ram is so adjusted that when *d* has descended and is at rest, it is close enough to grip the blank between its

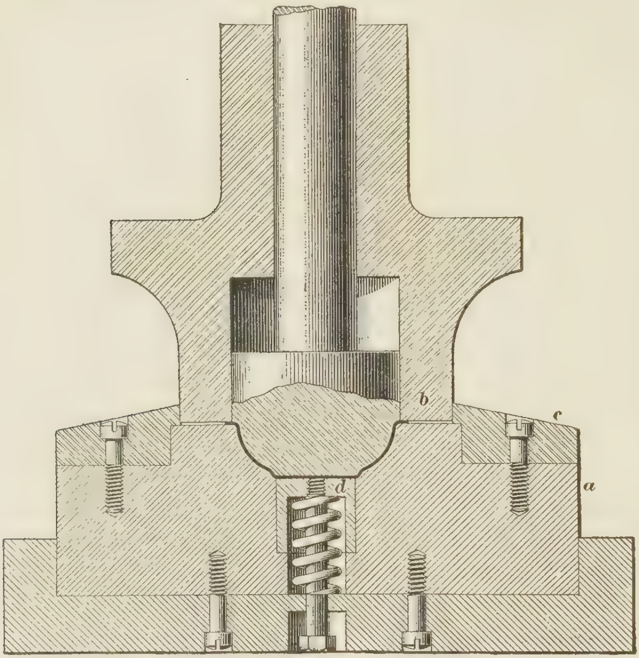


FIG. 42

lower surface and the upper surface of the die, and thus furnish the pressure necessary to prevent wrinkling. The drawing punch is to be so timed that it will not strike the blank until it has been confined by the blank holder. The cup is then drawn by the punch. The finished cup is stripped off by the sharp lower edge of the drawing die.

66. Drawing Work With Tapering or Curved Walls. So far, only the drawing of cups with walls at a right angle to a flat surface has been considered. Work may be drawn with tapering or curved walls, however, as, for instance, the

work shown in cross-section between the upper and lower parts of Fig. 42. By not drawing the metal entirely from between the blank holder *b* and the upper surface of the drawing die *a*, a flange is left on the open end of the work. The die shown is a combined cutting and drawing die; the cutting edge of the die *c* is formed on a removable ring, which is easily renewable in case of wear or accident. To eject the drawn work from the die, an ejector *d* may be fitted. This ejector may be spring-actuated, as shown, or it may be positively operated by some moving part of the press. Whether or not an ejector, often known as a *knock-out*, is to be fitted depends on the shape of the work. If it can easily be lifted out of the lower die, the ejector may be omitted.

The design of dies shown in Fig. 42 is intended for a double-action press. Combination dies may also be designed for the same work to use in a single-action press. These dies may be constructed on the same principles as the die shown in Fig. 40.

To prevent wrinkles from forming in the walls of work having a cross-section similar to that shown in Fig. 42, the pressure of the blank holder on the confined outer zone of the blank must be quite heavy. If wrinkles cannot be prevented from forming in the body, they may afterwards be removed by striking the work between a solid punch and die of the same shape as the work, thus ironing out the wrinkles.

67. Cutting, Drawing, and Embossing Combination Dies.—Cutting, drawing, and embossing combination dies may be subdivided into *spring-actuated*, *double-action-press*, and *triple-action-press dies*.

Spring-actuated, cutting, drawing, and embossing combination dies are used on a single-action press, the blank holder being operated by a spring.

Double-action-press, cutting, drawing, and embossing combination dies are used on a double-action press, the punches and blank holder being operated by two separate rams.

Triple-action-press, cutting, drawing, and embossing combination dies are used on a triple-action press, the punches and blank holder being operated by three separate rams.

68. For work like that shown in Fig. 43 (*a*), cutting, drawing, and embossing combination dies of the form shown in (*b*), may be used to cut the blank, draw the rim, and emboss the flat top in one operation, thus greatly reducing the time per piece below what it would be in case these three operations were

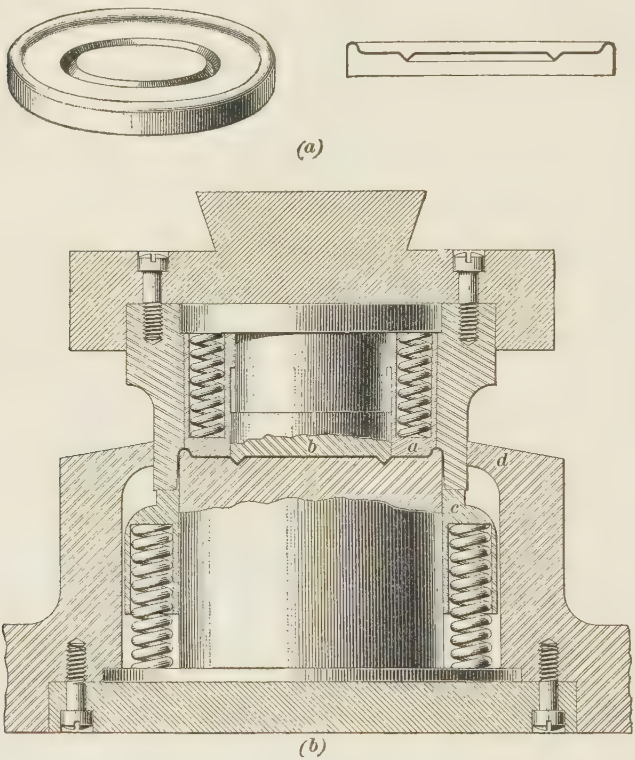


Fig. 43

performed in separate dies. The design of die to be used for this class of work depends on the type of press that is available.

For a single-action press, the design shown in Fig. 43 (*b*) is a satisfactory one. This design may be modified in various ways to suit conditions. In the illustration, the dies are shown together, with the work between them; when the dies are apart, the upper ejector *a* projects beyond the face of the embossing

punch *b*. The combined blank holder and ejector *c* in the lower die is then in its uppermost position. The pressure necessary for successful drawing is supplied by a number of heavy helical springs that may extend into recesses bored into the blank holder, to effect a saving in the height of the die.

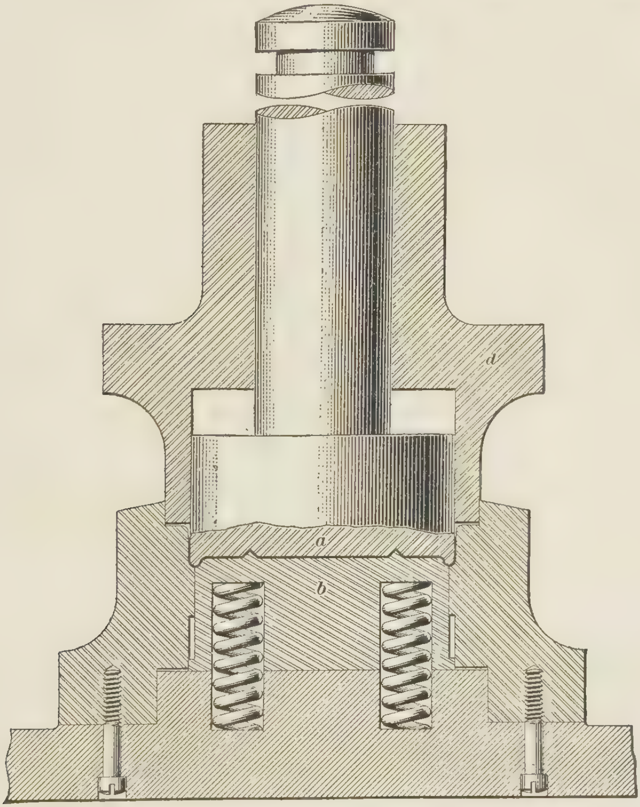


Fig. 44

For the same reason, the springs for the upper ejector may be placed within recesses bored into it. The cutting die *d* may be solid, as shown, or a small tool-steel ring may be attached to a cast-iron body. The point to be observed in making any combination die is to design it so that it is low in first cost, and that all wearing parts can be easily and cheaply renewed.

69. Should a double-action press be available, double-action press, cutting, drawing, and embossing combination dies, illustrated in Fig. 44, may be used for cutting, drawing, and embossing the piece shown in Fig. 43 (*a*). No stripper will be needed for the upper part, as the blank holder and cutting punch *d* will automatically strip the finished work from the drawing and embossing punch *a*. The embossing die *b* serves as an ejector, being actuated by the springs shown. The

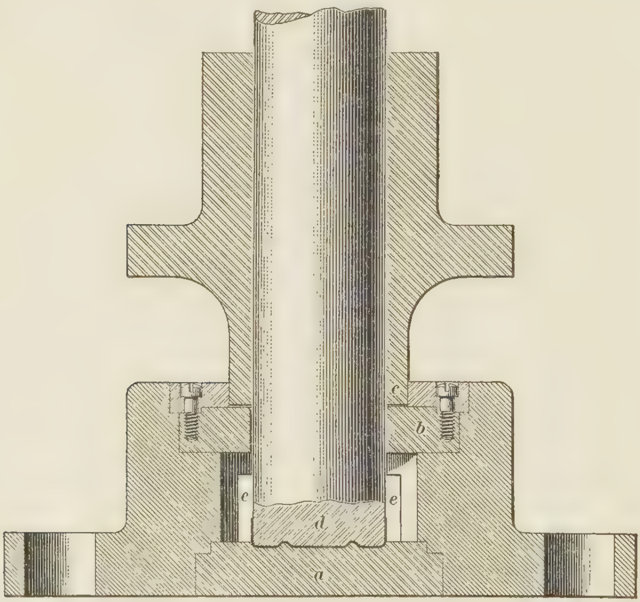


Fig. 45

blank holder and cutting punch are operated by the ram of the press and the drawing and embossing punch by the plunger. By comparing Figs. 43 and 44, it will be seen that there is far less work required to make the dies for a double-action press. The design shown may be modified in various ways, as deemed advisable. Referring again to Figs. 43 and 44, the lower part should be fitted with a suitable guide strip and gauge pin for the stock. These have been omitted in the drawing for the sake of clearness.

70. Both of the designs shown in Figs. 43 and 44 will discharge the finished work on top of the lower die. In many cases this is objectionable; the design may then be modified, as shown in Fig. 45, if circumstances permit. In this case, the embossing die *a* is entirely separate from the drawing die *b* and is placed some distance below it. The blank holder *c* is used to cut and hold the blank; the drawing and embossing punch *d* is first employed to draw the rim of the work and finally to emboss the bottom. As the punch ascends, the sharp lower edge of the drawing die *b* strips the work from it. The work then falls and is removed through the opening *e*. This design of die can be adopted only for work that can be pushed sidewise through an opening.

71. Should the shell as made by the die just described be of extreme depth, a very long stroke of the plunger *d* and consequently a longer time for completion would be required. Should a triple-action press be available, the embossing die *a* could be secured to the lower ram, which works up through the bottom of the press, and set so that it would meet the plunger *d* nearer the drawing die *b*. In this case the plunger *d* would make a shorter stroke and the work would be finished in less time. The dies used would be called triple-action-press, cutting, drawing, and embossing combination dies.

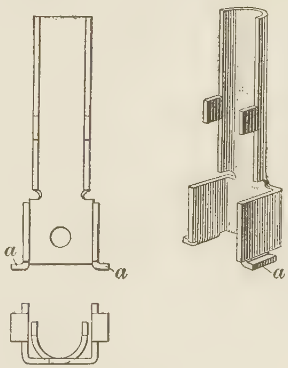


Fig. 46

PROGRESSIVE COMBINATION DIES

72. A progressive combination die for cutting, bending, and forming the piece shown in Fig. 46 is illustrated in Figs. 47 and 48. Fig. 47 (*a*) shows the die shoe containing the die; (*b*) illustrates the punch plate containing the punches; and Fig. 48 shows the punch and die complete. In Fig. 47 (*b*) and Fig. 48, *a* is the punch for cutting the profile, *b* the punches for bending the ears *a*, Fig. 46, at right angles, *c* the locating or traveling

dowels for the second operation on the piece, d the cutting-off punch, e the forming punch, f the locating or traveling dowels for the third operation on the piece, and g the stripper for stripping the piece from the blanking punch.

In Fig. 47 (a), a' is the blanking die; b' the bending die; c' the holes for receiving the dowel-pins c, Fig. 47 (b); d' the

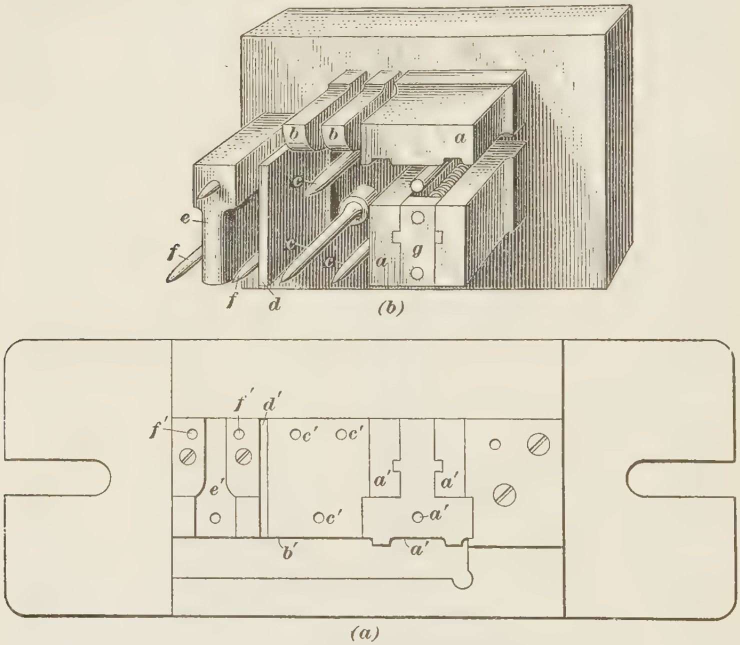


FIG. 47

cutting-off die; e' the forming die; and f' the holes for receiving the dowel-pins f, Fig. 47 (b).

73. If a slight variation in the length of the finished piece is permissible, stock is used whose width is equal to the length of the blank. In other cases, wider stock must be used, the blanking punch trimming the blank on its entire periphery. In the die shown, stock whose width equals the length of the blank is used.

74. The operation of the die is as follows. The strip is fed into the die from the right, the blanking punch a, Fig. 48, blanking

the strip as shown in Fig. 49 (*a*). The stock is fed along the approximate distance, and two of the dowel-pins *c*, Fig. 47 (*b*),

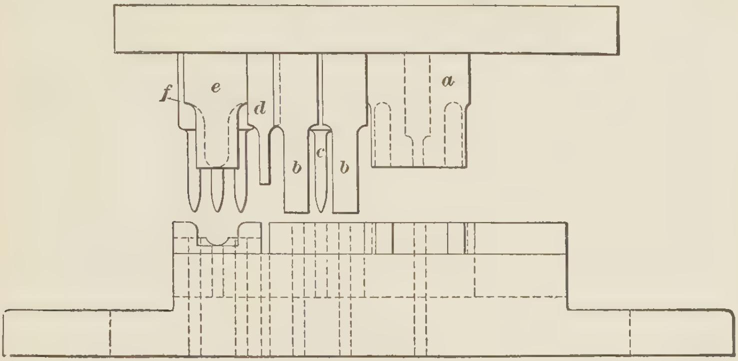


FIG. 48

straddle the blank while the third enters the hole in the blank. By using these three pins, the blank is accurately located for the second operation, which consists of bending down the ears *a*, Fig. 49 (*b*), and blanking another piece *c*. The strip is fed along further for the third operation, the blank being located sidewise by the dowel-pins *f*, Fig. 47 (*b*), and lengthwise by the pilot in the end of the forming punch. As the ram descends farther, the cutting off punch *d* severs the blank farthest to the left, an allowance *b*, Fig. 49 (*b*) and (*c*), being provided for cutting off. The forming punch also forces the blank into the forming die, finishing it as shown at *d* in (*c*).

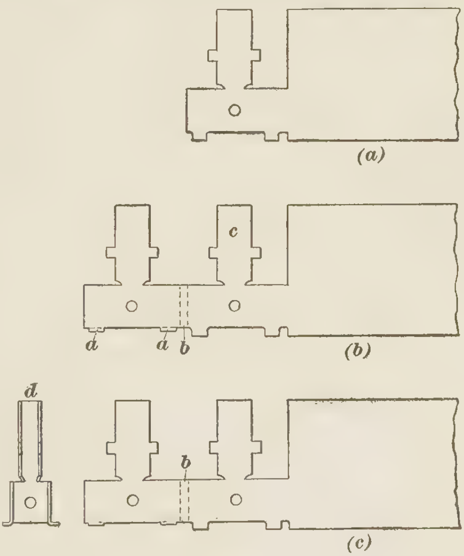


FIG. 49

75. It has been seen that three strokes are required to complete a single blank; but while finishing one piece the second and first operations are being performed on other blanks. Hence, one piece is finished at each stroke. By the use of this type of die, many operations may be performed on the blank. Stop-pins may be used instead of the long dowel-pins or pilots, but not as satisfactorily.

DISCHARGE OF WORK FROM DIES

76. The ejection of the work sidewise, through the opening *e*, Fig. 45, at the back of the die, is sometimes performed by a sliding pusher rod worked by the press. More often, however, the bed of the press is set in an inclined position of about 40° from the vertical, so that the work in such dies as are shown in Figs. 38, 39, 40, 42, 43, 44, and 48, may slide out by the action of gravity. It would not be good practice to depend on gravity for the discharge of the work from the die shown in Fig. 45, as the oil on the cup might prevent the work from sliding off.

MAKING PROGRESSIVE COMBINATION DIES

77. Let it be required to make the punch and die shown in Figs. 47 and 48. The parts of the die are made first, being machined on the shaper or miller and located in the die shoe. The punch plate is next laid against the lower part and the centers of all round holes located by the prick-punch method, as described in *Dies and Die Making*, Part 1. The prick punches must, of course, fit the holes in the die nicely. The outlines of the remaining openings in the lower part are now scribed on the face of the punch plate to locate approximately the holes for the shanks of the remaining punches. All the round punches and pilots are next put in the punch plate and entered in their respective dies and guides. The lower part is now used as a jig to scribe the outline of the blanking and forming punches. The blanking punches are now finished as described in *Dies and Die Making*, Part 1. The forming punch is more rigid if provided with a shank, but in this case

there is no adjustment of the punch when the shank is fitted to the punch plate, consequently, the shank is frequently omitted. With a shank on the punch, very careful transferring of lines from the forming die to the forming punch by means of a height gauge is required, all the punches being entered in their dies. When the forming punch is made without a shank, it is fitted to the forming die. It is then located centrally in its die, and is screwed and doweled to the punch plate. As each punch is finished it is left in the punch plate, thus giving as many guides as possible for fitting the unfinished punches.

HARDENING AND TEMPERING

HEAT TREATMENT OF TOOL STEEL

METHODS AND APPLIANCES

INTRODUCTION

1. Kinds of Steel.—Next to iron, the most important element in steel is carbon, because it has so great an effect on the properties of steel. If steel contains less than .75 per cent. of carbon it is usually softer and more ductile than steels containing greater percentages of carbon and is known as **mild steel,** *machinery steel*, or *low-carbon steel.* Steel containing from .75 to about 1.50 per cent. of carbon is ordinarily called **carbon tool steel** and possesses properties that render it a suitable material for cutting tools. In addition to carbon, steel often contains other elements, the purpose of which is to give certain desirable properties to the steel. A steel of this kind is called **alloy steel.** The elements most commonly found in alloy steels are tungsten, molybdenum, nickel, chromium, and vanadium. Small quantities of impurities, such as sulphur and phosphorus, are always present in steel.

2. Forms of Heat Treatment.—The properties of steel, such as hardness, brittleness, etc., may be changed by subjecting the steel to heat treatment, which consists in heating the steel to certain temperatures and then cooling it in various ways. For example, if a steel is so hard that it cannot be cut readily with metal-working tools, it may be softened by the form of

heat treatment called **annealing.** The same process may be used to relieve the stresses set up in a piece of steel during forging. These stresses tend to distort the work and may cause it to crack if they are not relieved. The heat treatment by which steel is made hard is known as **hardening.** A steel cutting tool may be made so hard that it will readily cut annealed tool steel, low-carbon steel, and other metals. After a piece of steel has been hardened, it may be too hard or too brittle for the work it must do. In such a case, the hardness may be reduced by the heat treatment known as **tempering,** or *drawing the temper.* The tempering operation also relieves the stresses set up during hardening.

3. Effects of Heat Treatment.—When a piece of steel is subjected to heat treatment for the purpose of annealing, hardening, or tempering it, the percentages of carbon, sulphur, phosphorus, etc. remain the same. The changes that occur are changes in the structure of the steel. Annealing produces a structure that renders the steel very strong and tough, yet soft. Hardening produces a finer crystalline structure and the resulting steel is very hard. The form of heat treatment known as tempering tends to reduce the hardness and yet makes the steel tough and springy.

4. Transformation Ranges of Carbon Steel.—The changes in the structure of a piece of carbon steel when it is subjected to heat treatment occur at certain well-defined points. For example, if a piece of steel containing exactly .85 per cent. of carbon is heated, its temperature will rise steadily; but when 1,355° F. is reached, the temperature will remain unchanged for a time, although the heating is continued, after which it will increase again. Steel containing exactly .85 per cent. of carbon is known as the **eutectoid,** or *eutectoid steel.* The temperature of 1,355° F. is called the **point of decalescence of the eutectoid.** It denotes the point at which, during heating, the structure of the steel undergoes a change. This change is a dissolving of the carbon in the iron. If the steel is now allowed to cool, the temperature will fall steadily; but when 1,250° F. is reached, the temperature will remain unchanged for a time, or

may rise slightly, and will then decrease again. This temperature, 1,250° F., is called the **point of recalescence of the eutectoid.** A brightening of the color may also be noticed at the point of recalescence. It denotes the point at which, during cooling, the structure of the steel undergoes a change, and the carbon crystallizes out of the iron. These points can always be recognized by the pause in the rise or fall of temperature that occurs when they are reached. At the point of decalescence, 1,355° F., the individual particles of the eutectoid are as hard and fine of structure as they can be made, while the steel, as a whole, is soft. A similar condition is that of a wet ball of sand or clay, which is soft, as a whole, while many of the individual particles that compose the mass are hard enough to scratch glass.

5. The point of recalescence of all carbon steels is the same, or 1,250° F. The range of temperature between this point and the point at which the necessary changes in structure occur to give the best hardening and annealing results, is called the **transformation range.** The upper limit of the transformation range varies with the composition of the steel. The transformation range of the eutectoid is from 1,250° F. to 1,355° F.; but for steels containing less than .85 per cent. of carbon the upper limit of the range is not the same. The upper limit of the transformation range of steels containing over .85 per cent. of carbon is the same as the point of decalescence. The values of the transformation range for various carbon steels are as follows:

Carbon in Steel Per Cent.	Transformation Range Degrees F.
.10 or less	1,250 to 1,606
.30	1,250 to 1,550
.45	1,250 to 1,430
.60	1,250 to 1,400
.85 and over	1,250 to 1,355

METHODS OF HEATING

6. Kinds of Flames.—In the heat treatment of tool steel, the steel is heated by direct contact with flames or by surrounding it with an atmosphere that is kept at a high temperature. The heat is usually obtained by burning some form of fuel that consists largely of carbon, as gas, oil, coal, coke or charcoal. The heating furnace is supplied with an air blast and the oxygen in the air unites with the carbon in the fuel, producing flame and heat. If the flame or the atmosphere contains free oxygen, it is an **oxidizing flame** or **oxidizing atmosphere**, and the oxygen will burn the steel, producing a black scale on its surface. If the flame contains unburned combustible elements that will unite with the oxygen of substances placed in the flame, it is called a **reducing flame.** As there is no oxygen in steel, the only effect of a reducing flame on steel is to raise the temperature. A **reducing atmosphere** is an atmosphere that, when heated to a high enough temperature, will act in the same way as a reducing flame; that is, it will remove oxygen from the substance placed in it. A reducing atmosphere will not affect the composition of steel.

7. It is not hard to tell whether a flame or an atmosphere is oxidizing or reducing in its nature. A small piece of wood may be put into the furnace containing the flame or the atmosphere to be tested. If it burns and disappears quickly, the flame or the atmosphere is oxidizing and the free oxygen has combined with the combustible in the wood. If the piece of wood merely turns black and chars, but does not burn, the flame or the atmosphere is reducing. If the flame or the atmosphere is neither oxidizing nor reducing, it is called a **neutral flame** or a **neutral atmosphere.** In the last case, no free oxygen is present, so that the flame or the atmosphere neither gives up nor absorbs carbon. The effect of a neutral flame or atmosphere on a piece of steel, therefore, is merely to cause a rise of temperature without altering the composition, as in the case of a reducing flame. A flame is more likely to be either oxidizing or reducing than neutral; consequently, to make sure

that there will be no oxidation, a reducing flame or atmosphere should be used to heat steel.

8. Heating in Forge Fires.—Practically all steel work, including tool dressing, and hardening, and tempering, was formerly done in an ordinary forge fire. Certain precautions, however, must be observed in using such a fire in order to insure good work. The fire must be very deep; that is, there must be a large body of incandescent coke between the tuyère and the tool, so as to prevent the blast from burning out the carbon in the surface of the steel. Frequently, what is known as a *closed*, or *oven*, *fire* is used for some classes of work; but ordinarily a high open fire will be found satisfactory. Sulphur will injure the quality of any tool steel; hence, for heating this class of steel, a fuel low in sulphur should be used. For this reason, charcoal is the best fuel; but its cost and the difficulty in maintaining the desired heat continuously prevent its use in most blacksmith shops. If the coal does contain some sulphur, its injurious effect can be reduced by using only coke for that part of the fire which is under and around the tool being heated. The burning of the coal to coke drives off much of the sulphur.

9. Heating in Tube or Muffle in Forge.—In order to prevent a loss of carbon, the steel is sometimes heated in a tube or a piece of pipe laid in the forge and brought to the desired heat. Sometimes a cast-iron box, called a *muffle*, is used for this purpose. If the muffle is closed at one end, so that there cannot be a draft of air through it, the heating will be done in the presence of such a small amount of air that the surface of the steel will not lose its carbon; then, too, the muffle will protect the steel from any sulphur in the fire. When the tube is used, the blacksmith frequently grasps the end of it in his tongs and gives it a partial rotation; by doing this every minute or two, round steel will be heated more uniformly than if left at rest. In the case of rectangular work, it is generally necessary to leave the tube in one position.

10. Steel may be heated, by a patented process, in a closed tube containing a gas rich in carbon in order that the surface

of the steel will not lose its carbon, as would be the case if heated in air. Natural or artificial gas is supplied to the tube through a connection to the cap screwed on one end of the tube, the cap at the opposite end being provided with a hole, about $\frac{1}{16}$ inch in diameter, through which the gas is allowed to escape and burn while the steel in the tube is being heated in the furnace. Practically the same results can be obtained by heating the steel in the presence of gas generated in the tube or muffle by heating à little finely divided coal or resin put into the tube with the steel, the gas filling the tube and driving out the air, thus protecting the steel while it is being heated.

11. Heating by Oil or Gas.—To feed solid fuel to the proper point whenever needed and to remove the ashes as they accumulate without producing an uneven heat is by no means an easy task. Oil or gas is better than a solid fuel for heating steel because a uniform heat can be maintained, oxidation of the steel prevented, and the furnaces used intermittently with convenience. In order to prevent oxidation of the steel, the supply of gas need only be so adjusted that there will be a very slight excess of gas present to burn beyond the combustion chamber proper. The presence of this gas excludes all air from the steel and consequently all oxidizing action. By properly locating the combustion with relation to the heating space, it has been found possible to construct furnaces capable of maintaining very high temperatures.

12. Heating by Electricity.—Electric furnaces are also used to heat steel. With them, as no air blast is used, the atmosphere is normally reducing, and no difficulty is experienced in getting a neutral atmosphere or in maintaining a uniform temperature. The neutral atmosphere is obtained by admitting outside air to the furnace chamber. Such furnaces may be quickly brought up to the desired temperature, and are therefore well suited to intermittent work. The temperature of the furnace may be quickly adjusted to suit the work. The heating chamber of the electric furnace is clean and free from flame and injurious products of combustion, and the heat is so equally radiated that the temperature is practically the same in every

part of the chamber. Electric furnaces are free from noise in operation and are easily controlled.

13. **Heating in Melted Barium Chloride.**—In order to prevent oxidation, steel is frequently heated in a bath that will exclude the air. Barium chloride is used for this purpose. It is a substance that looks very much like table salt, and in the commercial form melts at about 1,635° F. It is usually melted in a steel or a graphite crucible with about 2 per cent. of soda ash. The soda ash prevents, to a considerable extent, the rising of chlorine fumes from the bath. Oil, coal, gas, coke, or electricity may be used for the heating. Uniform temperatures are easily maintained in this bath, which is especially well suited for heating long, slender tools that must be brought to a high temperature, as little trouble is experienced from warping when this method is used. The barium chloride that sticks to the tools is easily brushed off. The fumes should be led away by means of a hood and a stack.

14. **Heating in Molten Lead.**—Molten lead is sometimes used as a hardening or tempering bath. The lead can be melted in a cast-iron pot or a plumbago crucible heated in the forge, or the pot may be heated in a specially constructed furnace. The steel must be left in the bath until it is heated throughout to the desired temperature. As steel will float in molten lead, some means must be furnished for keeping it submerged in the lead bath; also, a hood must be provided to carry off the lead fumes.

15. **Heating in Charcoal.**—For heating steel for hardening, some manufacturers use muffle furnaces in which the muffles are filled with charcoal; the steel is placed in the heated charcoal. The advantage claimed for this process is that the steel, being constantly surrounded by very pure carbon fuel at a very high temperature, will have a tendency to absorb carbon rather than to give it up, and hence there is absolutely no danger of burning the carbon out of the steel. This method is used especially when heating steels that contain large percentages of carbon.

16. Ideal Fuel for Hardening Furnaces.—The ideal fuel for a hardening furnace is one the supply of which can easily be controlled, so as to maintain a uniform temperature and at the same time insure a reducing fire under all circumstances. The only way in which this can be accomplished with a solid fuel is by having a very deep fire and a grate or tuyère carefully designed to prevent the localization of the blast, which might force excess air through the fire. The difficulty of maintaining a uniform temperature with solid fuel, as well as the fact that a furnace using the solid fuel cannot be used intermittently, has resulted in the employment of gas, oil, or electricity for heating work for hardening and tempering.

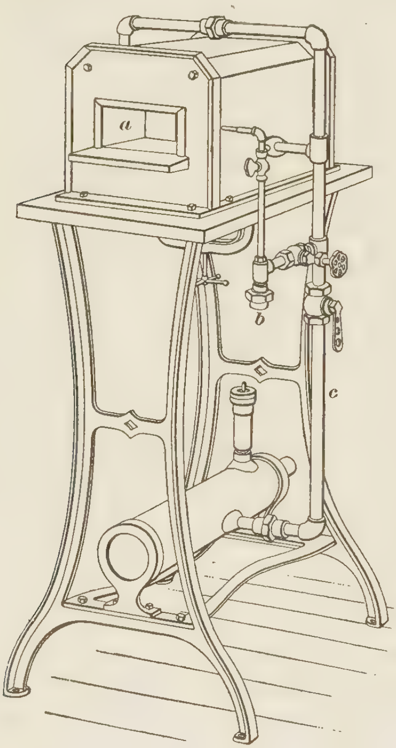


Fig. 1

HEATING EQUIPMENT

17. Tool-Room Forge.—When work of medium size is to be heated, a forge like that shown in Fig. 1 will give good results. It is commonly known as a tool-room forge and is made in several sizes, with corresponding variations in the size of the heating chamber. The work is placed in the heating chamber through the door *a*. The two burners, one on each side of the furnace, are supplied with gas through the pipe *b* and with air through the pipe *c*, the supply of both air and gas being controlled by suitable valves. This furnace may be used for hardening, tempering, or annealing.

18. Heating Furnace for Slender Tools.—A properly constructed oil or gas furnace like that shown in Fig. 2 is often used to heat taps, reamers, drills, and other long, slender tools. The furnace consists of a cylindrical metal casing lined with fireclay or firebrick and provided with three or four burners that project the mixture of oil or gas and air into the furnace, so as to cause the flame to circulate about the work. The air valve is shown at *a* and the oil or gas valve at *b*, the air being under a suitable pressure, usually about 1 pound per square inch. The

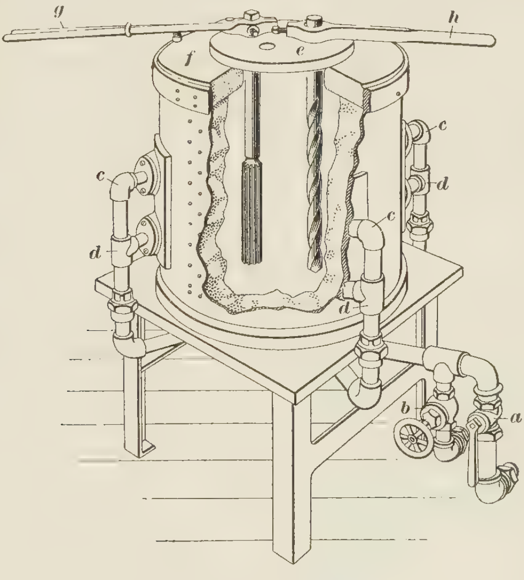


Fig. 2

burners are shown at *c* and *d*. In the center of the top *f* of the furnace is a large hole covered with a circular plumbago cover *e*, which is pierced with holes through which the work is inserted. A pyrometer may be put through one of the holes to measure the temperature. The tools are held by suitable tongs *g* or by special dogs *h*. This type of furnace is adapted to comparatively long tools, that require only the cutting ends to be hardened, but it has the advantage of keeping them straight and insuring a uniform heat. When taps, reamers, or other small pieces

are to be hardened throughout, a barium-chloride bath or a muffle or an oven furnace must be used.

19. Crucible Furnace.—The crucible furnace, one form of which is illustrated in Fig. 3, is used to melt the barium chloride or lead used to heat the tools. It may also be used without a bath, the crucible serving as a muffler to protect the work from direct contact with the flame. The furnace shown is gas-fired. It consists of a metal casing *a*, view (*a*), a firebrick lining *b*, a fireclay stand *c* on which a crucible *d* rests, a firebrick cover *e* that is removed when a crucible is to be inserted or taken out, a firebrick cover *f*, and burners *g*. Air enters the furnace through the pipe *h* and gas through the pipe *i*, the supply of both being controlled by suitable valves. The jets or burners *g* enter the furnace at an angle, as shown in the sectional view (*b*), the object being to secure a rotary motion of the flame, which motion insures uniform heating of the entire contents of the crucible. The burned gases escape through the vent *j*, view (*a*), and the openings *k* and *l*. The handles *m* and *n* are for convenience in moving the covers. A hood is placed over the furnace to carry off the fumes.

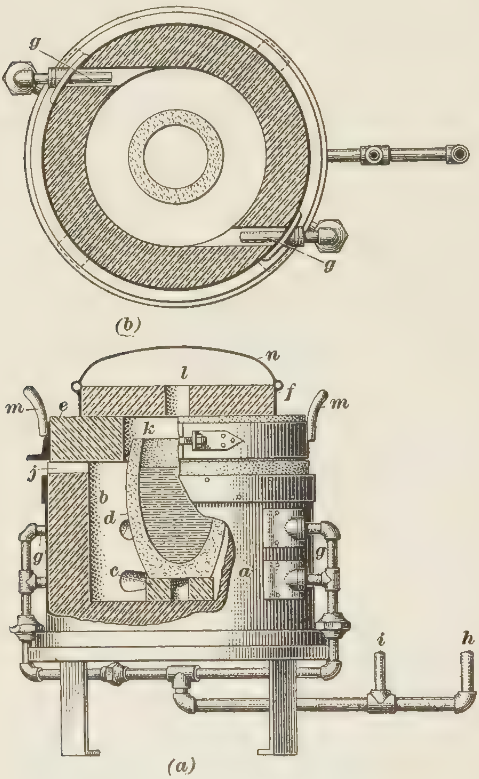


FIG. 3

20. Oven Furnace.—In Fig. 4 is shown a form of oven furnace that is well adapted to heating milling cutters and similar tools. Most milling cutters, especially formed milling cutters, require careful treatment, both in heating and hardening, in order to prevent cracks and injury to their sharp edges. The furnace consists of a casing *a* that surrounds both the combustion chamber and the heating chamber, the two chambers being separated by a fireclay slab *b*. The burners *c* are arranged along both sides of the furnace and are supplied with air and gas through suitable pipes controlled by the valves *d* and *e*. The gases mingle and partly burn beneath the slab *b*, the products of combustion ascending around the edges of the slab into the space where the work is located. The work *f* is supported on a block *g* in the center of the furnace. Care must be taken to see that a reducing flame only is present in the heating chamber. The front of the furnace is closed by a door *h* provided with a small hole *i* for observing the temperature of the work. The burned gases escape from the furnace through a vent at *j*.

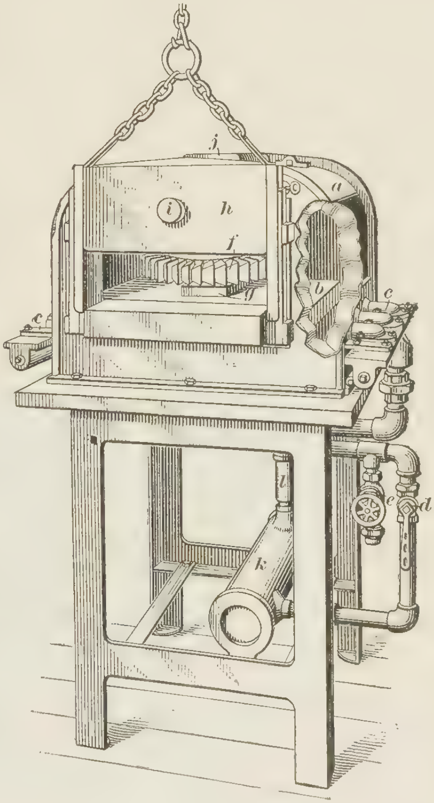


FIG. 4

21. The supply of air for the furnace passes through an air drum *k*, Fig. 4, to which is attached a relief valve *l* for

controlling the air pressure, which may be varied as required by weighting the valve with small, perforated, $\frac{1}{4}$-pound disks that are slipped on the end of the vertical valve stem. Two disks are required to secure an air pressure of 1 pound, the unweighted valve providing a minimum pressure of $\frac{1}{2}$ pound.

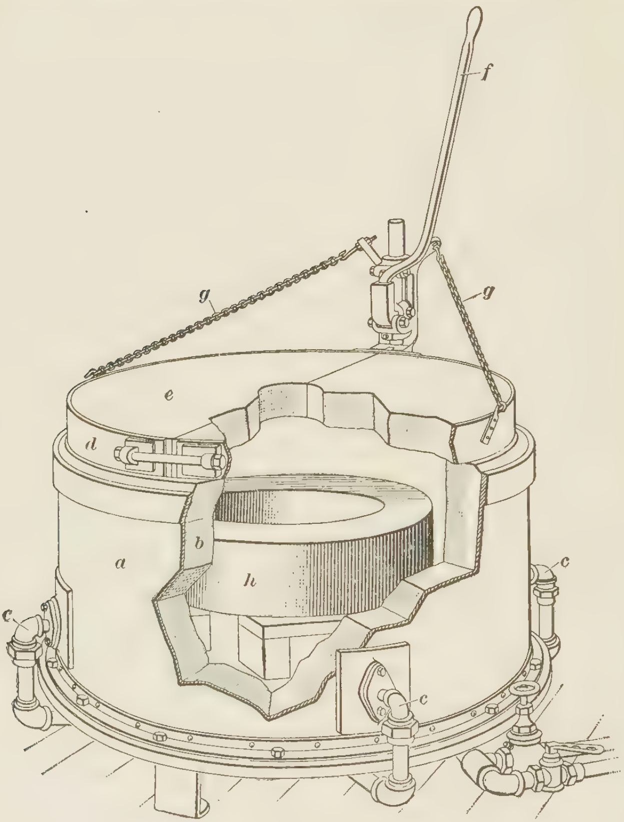


Fig. 5

The required air pressure is reached when the valve just lifts and steadily blows off while the air cock *d* is wide open. The work should be placed in, as well as taken from, the furnace with special tongs that bear on the sides of the cutter without touching the teeth. Such a furnace will be found very efficient for heating large carbon-steel cutters.

22. Circular Annealing and Hardening Furnace. Many forms of gas furnaces have been developed for special work. For heating large circular work, for annealing or hardening, a furnace of the form shown in Fig. 5 will be found very convenient. It consists of a circular metal casing *a* with a suitable firebrick lining *b*. The burners *c* are arranged in such a manner that they enter the furnace tangentially so as to

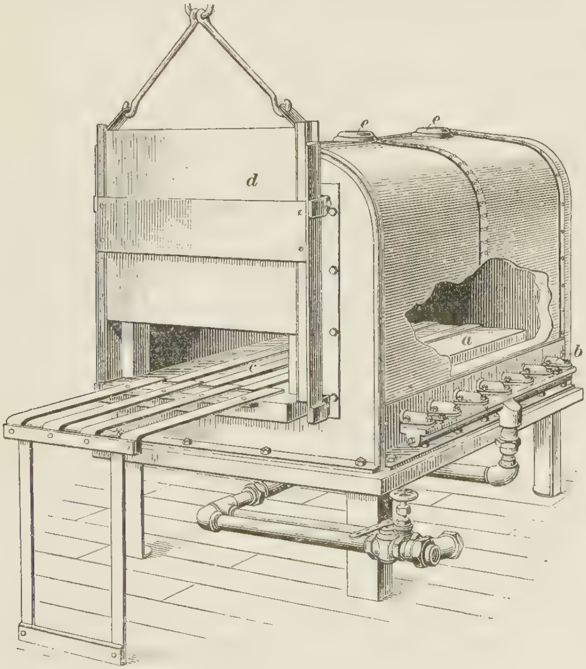


FIG. 6

cause the flame to travel around in the furnace, thus insuring uniform distribution of the heat. The cover consists of an iron band *d*, inside of which are clamped firebrick tiles *e*. It is so arranged that by throwing the lever *f* back slightly the cover will be lifted off the furnace by the chains *g*, when it may be swung to one side, giving access to the work and to the entire top of the furnace. The work *h* is supported in the center of the furnace on suitable firebrick tiles.

23. Oven Annealing Furnace.—In any shop in which a considerable amount of high-carbon steel is used, provision must be made for the annealing of the steel in packing boxes.

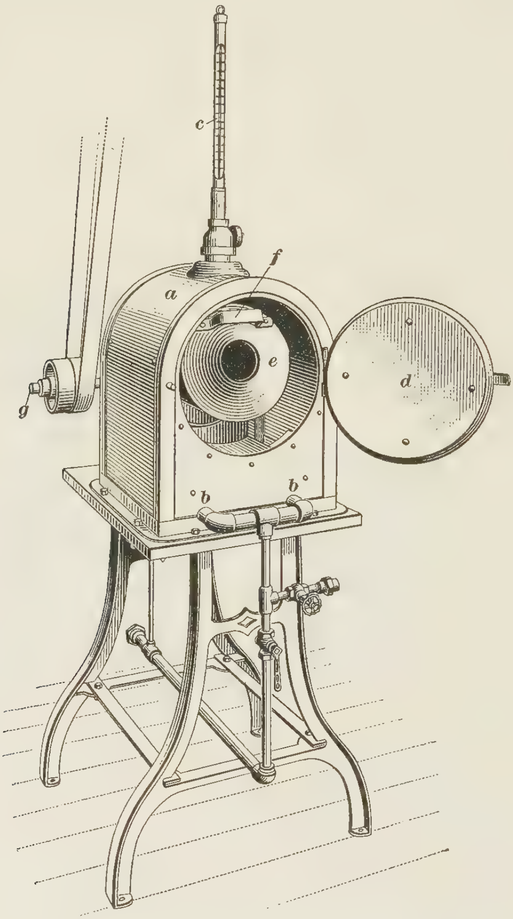


FIG. 7

A furnace, shown in Fig. 6, suitable for heating such packing boxes, consists of an oven below whose tile floor *a* there is a combustion chamber with a series of burners *b* arranged along each side. Iron bars *c* are usually placed on the tile floor to

protect it from wear as the packing boxes are slid in and out. The door *d* is generally arranged with a counterweight, so that it can be opened and closed easily. The products of combustion escape through the openings *e* in the top. The capacity of this furnace is sufficient to accommodate boxes or pots large enough to hold any ordinary work.

24. Tumbling-Barrel Furnace.—To insure a uniform temperature for small work, many special types of furnaces have been developed. One of these, shown in Fig. 7, is used for heating steel in drawing the temper. The furnace consists of an ordinary oven with a metal casing *a* and burners *b*, the temperature of which can be determined by means of a thermometer *c*. The temperature registered by the thermometer will not be the same as the temperature of the interior of the furnace; but the proportion between the two will be always the same, and if experiment has proved that a certain temperature on the thermometer *c* is right for a certain class of work, this temperature can be recorded and always used when tempering that class of work. The front of the oven is closed by a door *d* when the furnace is in use. Inside the furnace is a tumbling barrel *e* supported on a shaft passing through the back of the furnace; this tumbling barrel can easily be detached and lifted out by means of the handle *f*. The supporting shaft is rotated by a pair of bevel gears, one of which is on the shaft *g*. When in use, the work is dropped into the tumbling barrel, or drum, *e*, and the machine started. The work can be observed from time to time by opening the door *d* and noting the color of the work, or by removing a piece and testing it. When the proper conditions have been determined, it is not necessary to open the door *d* until the thermometer *c* has indicated the required temperature for a sufficient length of time to draw the work to the desired temper.

25. Sand Temper-Drawing Furnace.—In some cases, good results can be obtained in drawing the temper of small work by exposing it to a shower of heated sand. A furnace for doing this class of work is shown in Fig. 8. It consists of an oven furnace in which is arranged a tumbling barrel, or

revolving cylinder, the inside surface of which is fitted with a series of boxes that carry the sand up and then pour it in a shower over the work. Clean white sand or ground flint is generally used for this purpose, and the work itself slides or rolls forwards on the sand in the bottom of the drum as the latter slowly rotates. The rotating drum *a* is driven by a worm-wheel and worm, as shown. The temperature may be determined by the thermometer *b*. The burners are arranged in a chamber below the revolving drum, the gas being lighted at the hole *c*.

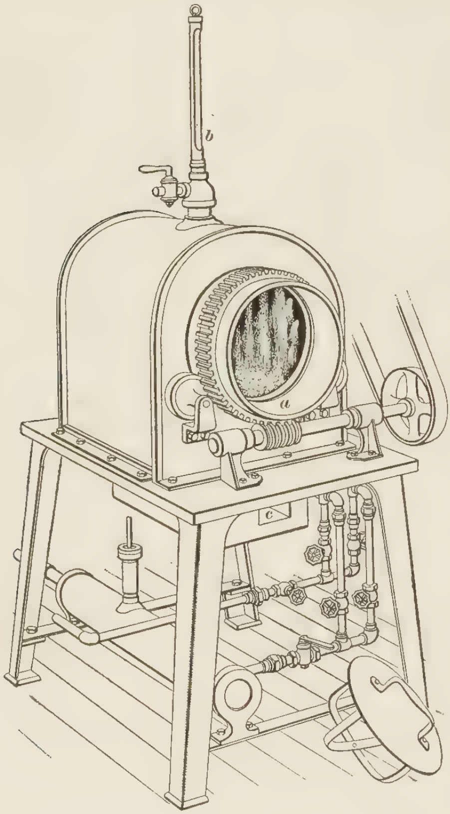


FIG. 8

26. Air-Tempering Furnace.—For tempering certain classes of work, there is frequently used a furnace so arranged as to heat air as it passes through pipes or between plates situated in the heating chamber. The heated air is then conveyed to the oven or the chamber in which the work to be tempered is placed.

27. Chain-Conveyer Furnace.—For hardening or tempering work of irregular form, many different styles of chain-conveyer furnaces have been brought out. One of these is shown in Fig. 9. The furnace body proper is heated by a series of burners *b* and the work to be tempered is placed between

the cast links *i*, at the right-hand end of the furnace. The temperature of the furnace and the speed of the chain are so regulated that the work is heated to just the required degree while it is passing through the furnace. When the work has been heated, it is dropped automatically into a cooling bath *k*. Furnaces of this class are used for heating a great variety of work, for either hardening or tempering.

28. Oil-Tempering Furnace.—For drawing the temper in oil, special oil baths placed over suitable heating furnaces

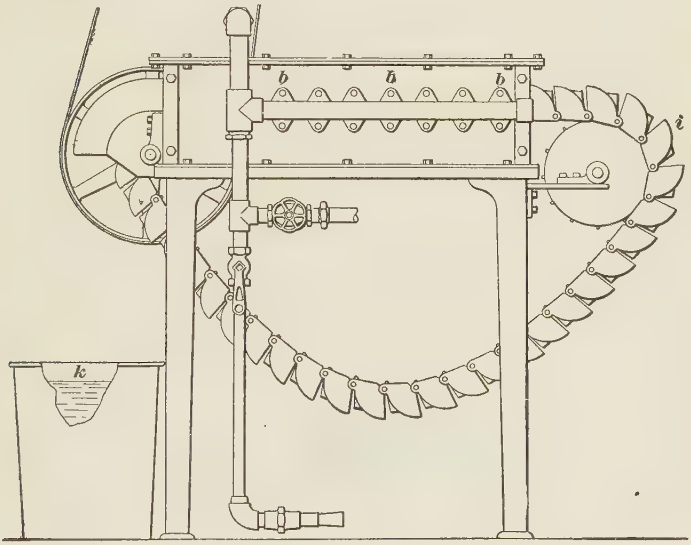


FIG. 9

are very frequently used. One form of gas-fired oil-tempering bath is shown in Fig. 10. It consists of a metal casing *v*, in which is suspended an oil tank *s* containing a wire basket. One of the handles of the basket is shown at *k*, and on the floor in front of the furnace is an empty basket. Air and gas are supplied by the pipes located on each side of the furnace, the gas being lighted through a hole near the plug *n*. The temperature of the oil bath is gauged by the thermometer *l*. When a basketful of work is placed in the oil, the temperature of the bath

will fall, and care must be taken to see that sufficient time is allowed for both steel and oil to come to the desired temperature.

29. For large or long work, oil-tempering baths frequently take the form of deep cylindrical pots, which may be heated over a coke or a coal fire or by means of oil. As the style of furnace required depends entirely on the character of the work that is being done, no general rules for the selection of oil-tempering furnaces can be given, but there are certain precautions that should always be taken. With gas-burning furnaces,

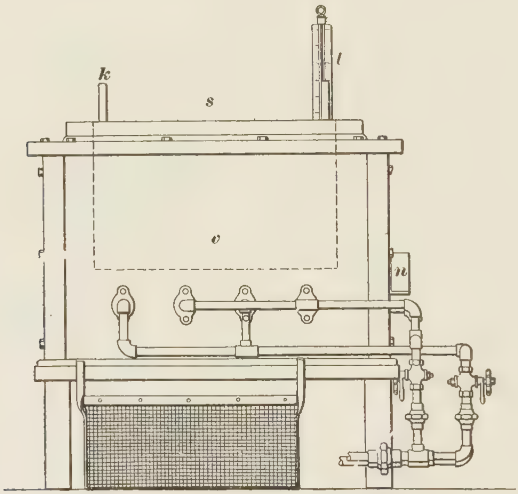


FIG. 10

the gas and air valves should be so located that the boiling over and ignition of the oil in the tempering tank will not prevent the operator from shutting off the fire under the furnace. In any oil-bath furnace, there should be provided a cover that can be placed over the tank quickly to extinguish any fire that may start. When an oil-bath furnace is heated with solid fuel, the bath should be so located that the boiling over of the oil will not carry it into the fire in the heating chamber. By observing these precautions the tempering tank becomes a relatively safe device, even when the oil is to be heated to a very high temperature.

30. Tool-Dresser's Forge.—When the steel is heated in a forge using solid fuel, it is well to have a specially constructed forge with a hood. The reasons are that all tool dressing requires a very deep fire and that the hood will, to a considerable degree, protect the work from drafts. A good form of this style of forge is shown in Fig. 11. A heavy cast-iron base *a* supports the forge pan *b*, over which is mounted a hood *c*. At the back of the hood is a rectangular opening *d*, through which long work is allowed to project. Blast for the forge is supplied through the pipe *e*. In front of the hood is a large rectangular opening *f*, giving ready access to all parts of the forge pan. The top of the forge *b* should be about 3 feet in diameter, and the hood about 24 inches high up to the conical part leading to the stack. Crushed coke is generally used as a fuel in such a forge, although for some work charcoal may be used.

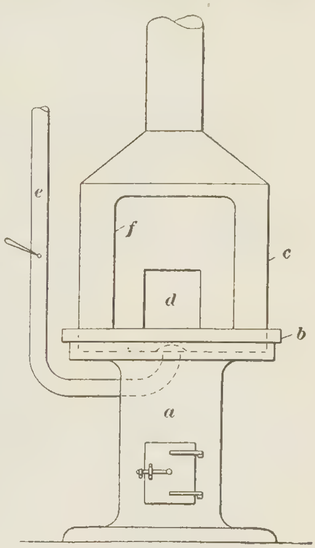


FIG. 11

31. Coke-Fired Hardening Furnace.—In many cases, a hardening furnace using coke as a fuel is desired; such a furnace is shown in detail in Figs. 12 and 13, the left-hand portion of Fig. 12 being a front view and the right-hand portion a section. Fig. 13 (*a*) is a longitudinal section, and (*b*), a plan of the grate and a section through the fire-door. The grate bars are of the herring-bone pattern. In any furnace of this kind, it is very important that the surface of the grate should remain level and that the bars, as far as possible, should be kept from warping. Warping of grate bars causes an unequal distribution of the air, resulting in an unequal heating and, at times, burning of the steel. Clean, hard coke should be used for such a furnace, unless for special work good hard charcoal is preferable. The fire should be kept at such a level that

its upper surface will be level with the bottom of the fire-door or slightly above it.

32. Electric Furnace.—One form of electric furnace, together with the auxiliary apparatus, is shown in Fig. 14. The amount of electric current used by the furnace is indicated on the ammeter *a*, and the circuit may be made or broken, as desired, by throwing the switch *b*. A circuit-breaker *c* opens the circuit automatically when the current becomes excessive. The current passes through the transformer *d*, where the voltage, or pressure, of the line voltage is reduced to from 20 to 28 volts, and thence to the heating elements in the furnace. A pyrometer is inserted into the heating chamber through a hole that extends from the rear of the heating chamber to the outside. The pyrometer wires, or leads, together with the leads to the transformer, pass through the conduit *e* to the switchboard *f*. The furnace temperature is indicated on the galvanometer *g*. The furnace is thoroughly insulated against loss of heat by radiation by a firebrick lining on all sides. The door *h* is lined with firebrick and is counterbalanced by the weight *i*, so that little effort is required to move it up or down. A small peep hole with a swinging cover *j* enables the operator to see the interior of the furnace.

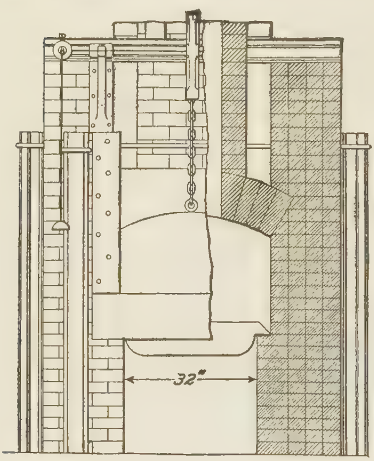


Fig. 12

33. A draft hole extends from the top and rear of the heating chamber, Fig. 14, to the top of the furnace, and a movable cover is provided, by means of which the hole may be closed, if desired. The atmosphere of the furnace chamber is normally reducing; but it may be changed to neutral by opening the draft hole and letting in a small amount of air at the door. If a larger quantity of air is admitted, the atmosphere will be

oxidizing. The electrode clamps k through which the current passes would become hot in use if steps were not taken to prevent heating. The prevention of heating is accomplished by supplying the clamps with water-jackets. The water enters

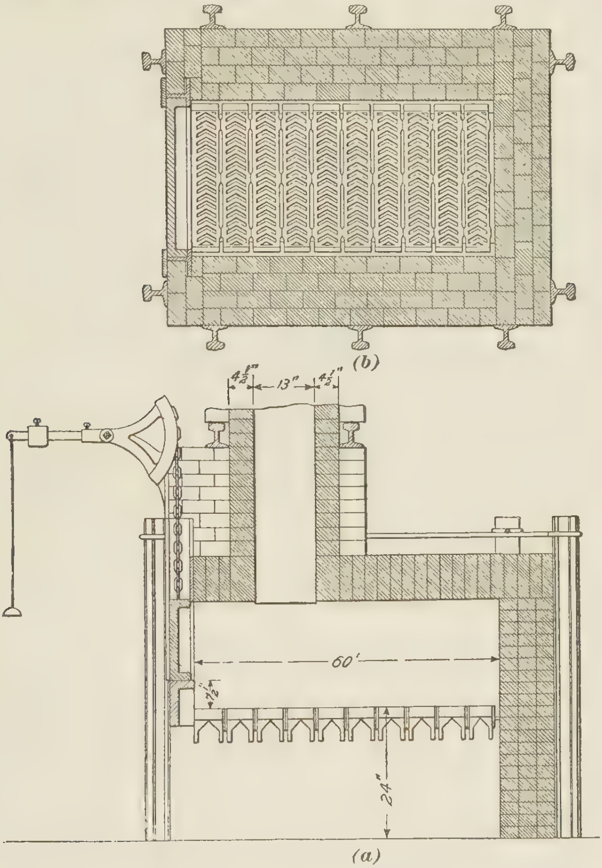


Fig. 13

through the hose l and leaves through the hose m. The furnace temperature is regulated by adjusting the hand-wheels n. Turning them so that the electrodes are forced upwards causes an increase both in the heat supplied and in the current consumption. Turning them in the opposite direction causes a decrease

in the heat supplied and in the current consumption. The temperature of the furnace can be brought up to 2,500° F. in about $1\frac{1}{4}$ hours. Owing to the definite relation between the current and temperature, that is, between the ammeter and pyrometer readings, the ammeter is very useful to the operator

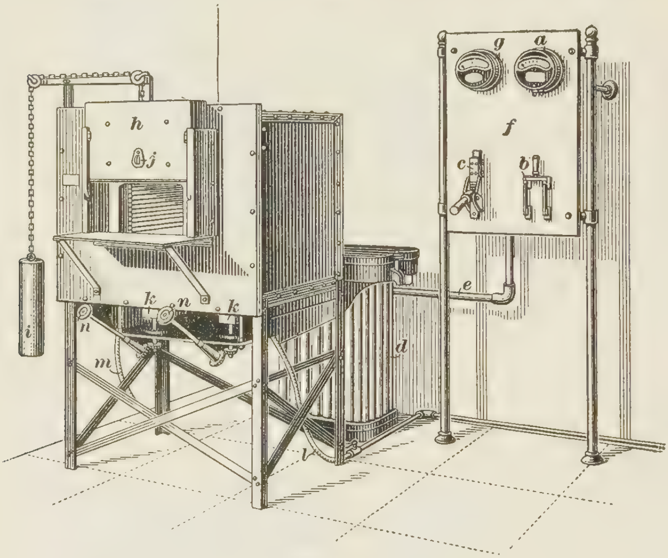


FIG. 14

in quickly regulating the furnace. Knowing the ammeter reading corresponding to the desired temperature, he can readily set the furnace to produce that temperature by adjusting the hand wheels to bring the ammeter reading to the known point.

HARDENING AND TEMPERING BATHS

34. Quenching Tanks.—In many shops, a barrel or any other convenient receptacle is used to hold the quenching solution. If much hardening is to be done, especially when brine is used, it is well to have a large tank that can be covered, when not in use, to exclude dust and dirt. The temperature of the brine may be controlled either by suitable steam and cold-water pipes passing through the bath, or by surrounding the

bath by a tank of water maintained at the desired temperature. In most cases, the bath, in continuous use, must be cooled in order to keep it at the proper temperature, which may be accomplished by flowing cold water about the bath. Fig. 15 shows a plan and side and end elevations of a quenching tank, in which *a* is a large water tank and *b* the bath proper. The water flows into the tank *a* through the pipe *c*, and the overflow water passes out through the pipe *d*. It will be noticed that the pipe *c*

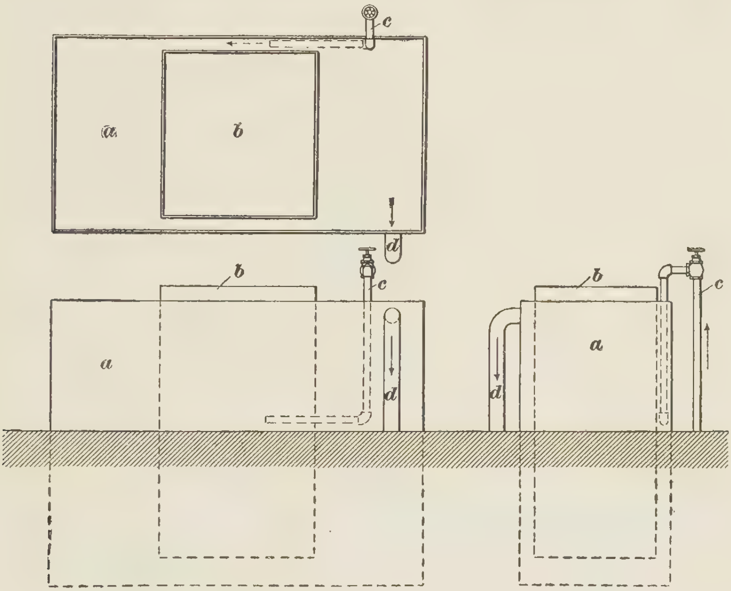


Fig. 15

is brought into the tank in such a way as to insure the circulation of the water about the bath *b*. If for any reason the bath must be maintained at a temperature above that of the inflowing water, it may be necessary under some circumstances to warm the bath, and in this case a steam pipe may be placed in the tank *a*.

35. Circular tanks having double walls are also frequently used, being so arranged that there is a circulation of water between the walls. In some cases, the tanks are provided with

air pipes passing down the sides and along the bottom for injecting air into the bath through a large number of very small holes. The air pipes are arranged in the central part of the tank and cause the part of the solution in the center to rise and that next the walls to descend. The air serves not only to circulate the solution and so keep it at a uniform temperature, but also to aid very greatly in cooling it.

36. An apparatus specially designed for hardening tools is shown in Fig. 16. It consists of a cylindrical tank *a* containing

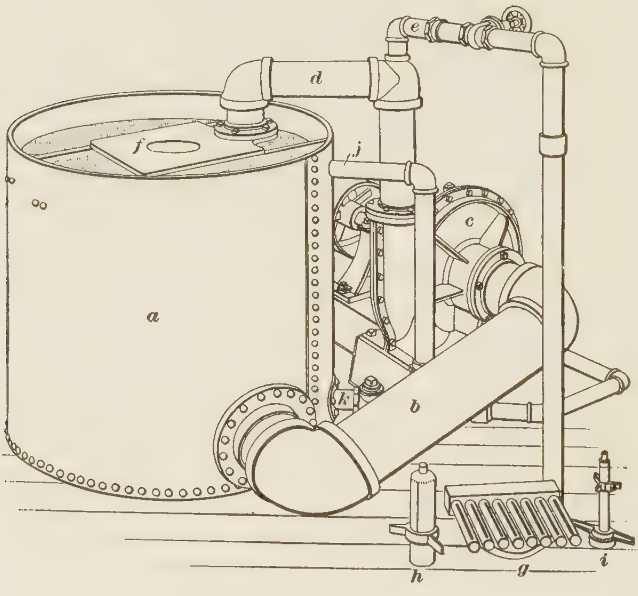


FIG. 16

a quenching solution, which is pumped out of the bottom of the tank, through the pipe *b*, by the centrifugal pump *c*, and back into the tank through the pipe *d*. Once the solution enters the tank, the direction of the flow is governed by the character of the work to be hardened; in the case of cylindrical work, proper fixtures may be used to direct the water against the surface of the work in jets. The work is put in through the hole *f* in the center of the tank. For hardening the surfaces

of flat dies, the special attachment shown at *g* is used, being placed some distance below the surface of the water and arranged to direct sprays of water against the bottom of the die. The special fixtures shown at *h* and *i* are used when hardening the inside of the cylindrical pieces, rings, or cutting dies. Provision is made for supplying any additional water that may be required from the regular waterworks system through the pipe *e*. An overflow is provided at *j*, and a drain pipe at *k*.

37. The tank shown in Fig. 16 can be used with clear, cold water, with a salt solution, or with oil. When the same solution is used over and over, an auxiliary tank for cooling it may be placed beside the hardening tank, the solution being allowed to overflow from the hardening tank into the auxiliary tank. Suitable cooling pipes, through which cold water is conducted, are arranged in the cooling tank, from which the pump draws its supply.

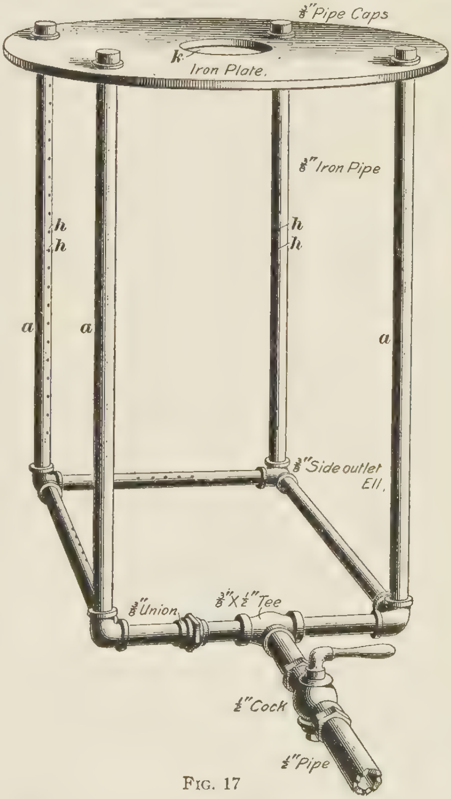


Fig. 17

38. Spraying Devices for Hardening.—In some cases where only a limited amount of hardening is done, a spraying device of the form shown in Fig. 17 may be used. This device is simply connected to the water main, and the work is introduced through the opening *k* in the iron plate at the top of the

device. The pipes *a* are pierced with holes *h* that direct the jets of water against the work. Frequently, the best results can be obtained by submerging the whole device in water, when the jets will serve to direct the water against the surface of the work and so break up any steam pockets that might form and have a tendency to cause soft spots on the work.

It is sometimes advisable to direct a stream of running water on one side of the work. A hardening tank arranged for work of this nature is shown in Fig. 18. The work *a* whose face *b* is to be hardened is supported on rods *c*. Water from a pipe *d* is then directed on the work. The water is collected in the tank *e* and is carried away through the overflow pipe *f*.

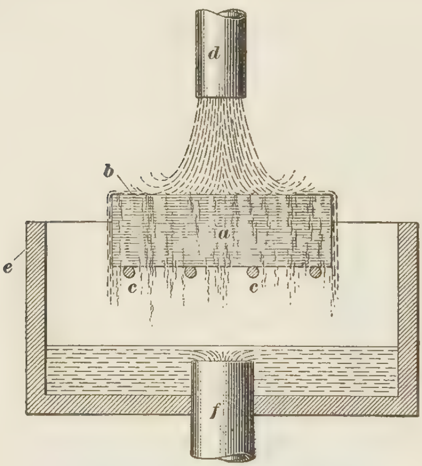


FIG. 18

39. Hardening Baths.—In many cases, clear, cold water is used as a hardening bath. The best results are said to be obtained from the use of soft water; rainwater is used considerably. The hardening bath should not be too cold; a very cold bath may extract the heat from the steel too quickly and cause cracks or breaks in the work. The temperature of the water for the general run of work should never be below 70° F., and for some purposes 80° to 90° would be better.

Brine, or a solution of common salt in water, is sometimes used when rapid cooling is required. Salt is added to the water to increase the rate at which the bath will extract the heat from the steel and to prevent, as far as possible, the formation of steam on the surface of the work. Brine that contains about 1 pound of salt to 3 gallons of water will be about right for hardening purposes. Tools hardened in brine will be as hard as it is possible to make them.

40. Various oils are frequently used in place of water as hardening baths, the most common being kerosene, fish, lard, linseed, cottonseed, and heavy mineral oils having a flash point of 300° to 340° F. The *flash point* is the temperature at which the oil will give off a vapor that will flash when lighted. Tools quenched in kerosene oil will, as a rule, be softer than they would be if quenched in water, although harder than if quenched in the other oils mentioned. Tools quenched in fish oil will be softer than they would be if quenched in kerosene oil, but harder than if quenched in lard, linseed, cottonseed, or mineral oil. Tools quenched in lard oil, linseed oil, or cottonseed oil will be softer than they would be if quenched in fish oil, though harder than if quenched in mineral oil. As a rule, hardening in oil leaves the work softer and freer from internal stresses than when water or brine is used.

41. Tempering Baths.—The tempering baths commonly used are oil, saltpeter, and lead. Work that is not to be heated higher than 500° F. is tempered in a thick cylinder oil having a flash point of 550° to 600° F. Work that must be heated to from 550° to 1,000° F. is generally tempered in a saltpeter bath made by mixing equal parts of potassium nitrate and sodium nitrate. Work that must be heated higher than 1,000° F. is generally tempered in a lead bath. The tempering may be done by placing the pieces in the bath and heating the whole to the proper temperature; or the bath may first be brought to the desired temperature.

42. When sufficiently heated, the pieces are removed from the bath and allowed to cool. Ordinary work is put in when the bath is at the proper temperature, which is read by means of a thermometer. The cold work reduces the temperature of the bath somewhat, and hence the work must be left undisturbed until the bath is brought back to the desired temperature. With heavy pieces, the bath must sometimes be maintained at the desired temperature for a considerable length of time. When the pieces are required to be clean and free from oil, they are removed from the bath and placed in a kettle containing a hot solution of soda. They are then dried and cleaned in

sawdust. Sometimes the work is taken directly from the bath and placed in the sawdust. In order to avoid cracking or breaking, complicated pieces of work having sharp angles are sometimes placed in the cold bath and the bath is then heated to the proper temperature.

HEAT-TREATING OPERATIONS

CARBON TOOL STEEL

43. Colors Corresponding to Temperatures of Steel. When heating steel, the temperature should be found by the use of accurate instruments. At times, however, such instruments are not at hand, and in such cases the temperature of the steel may be judged approximately by its color. The temperatures corresponding to various colors are given in Table I. The closeness with which temperature may be judged by color depends on the experience and the physical condition of the workman and on the light in which the work is done.

TABLE I

COLORS AND CORRESPONDING TEMPERATURES OF STEEL

Color	Temperature Degrees F.	Color	Temperature Degrees F.
Faint red	900	Salmon	1,650
Blood red	1,050	Orange	1,725
Dark cherry	1,175	Lemon	1,825
Medium cherry	1,250	Light yellow	1,975
Cherry or full red	1,375	White	2,200
Bright red	1,550		

44. Heating for Annealing.—The first step in annealing carbon steel is to heat the steel from 50° to 100° F. above its

transformation range. No matter how the steel particles may have been arranged previously, they are now as fine as they can be made. Should the steel be heated to a point below its transformation range, the annealing would not be effective; and if heated considerably above the transformation range, the particles would become coarse and continue to grow coarser while cooling. Steel heated much above its transformation range, but not burned, is known as **overheated steel.** It can be restored to its original state by being reheated to just above its transformation range. If carbon tool steel is heated above 2,100° F., its structure becomes very coarse and shiny, owing to the formation of a film of iron oxide about each individual grain. Steel thus heated is called **burnt steel** and it cannot be restored except by remelting. To anneal carbon steel, then, the steel should be heated to a temperature just beyond the transformation range, and maintained at that heat until it is heated throughout to that temperature.

45. Cooling for Annealing.—After the steel is heated, it may be cooled slowly in the air, in the furnace, or by packing it in some material that does not conduct heat away readily. For complete annealing, either furnace annealing or annealing by packing is necessary.

When air annealing is practiced, the steel is removed from the furnace, laid in a place free from drafts, and allowed to cool. Steel annealed in this way is not so soft as it would be if annealed by one of the other methods. The structure of the steel when air-annealed is moderately soft.

When furnace-annealed, the steel is left in the furnace after heating, the heat is shut off, the furnace is kept closed, and the work is allowed to cool with the furnace.

46. When annealing by packing is practiced, the steel after being heated is buried in some substance that does not conduct heat readily. An iron box nearly filled with slaked lime, ashes, or other similar material can be kept near the forge for this purpose. Care should be taken, however, to keep the material perfectly dry and warm. The steel should remain buried until it is cold.

47. When a large number of pieces of steel are to be annealed, as, for instance, blanks for taps, reamers, or other tools, they may be packed closely in cast-iron boxes or in pieces of pipe, using cast-iron chips, fine charcoal, or a mixture of the two, for the packing material. Sometimes the spent, or nearly spent, bone from the case-hardening furnaces is used for packing material. These boxes are then placed in an annealing furnace and heated to just above the transformation range. The draft is shut off and the furnace is allowed to cool slowly. The cast-iron chips conduct the heat better than an air space would, and support the pieces, thus preventing them from warping.

48. When the work must be removed from the furnace and allowed to cool outside, it is better to use spent bone as a packing material, because the work will cool much more slowly, owing to the inability of the bone to conduct the heat away rapidly. Sometimes when work is heated for straightening or forging, the pieces are taken from the forge and cooled in double sheet-iron boxes that have $\frac{1}{4}$ inch of asbestos between them. The cover also is double and is provided with a suitable hinge and counterbalance weight. As the work comes from the forging machine it is placed in the box, which, when full, is closed and left to cool, usually over night. While the stock cannot be so thoroughly annealed in this box as when heated to the proper temperature and allowed to cool in suitable packing material, the internal stresses will nevertheless be very greatly reduced.

49. Partial Annealing.—Small pieces of steel are sometimes partially annealed by being heated to the proper temperature and cooled slowly in the air until, when held in a dark place, only a very dull red is visible. The piece is then cooled in water. Although this process will usually soften the steel, it is a less reliable method than the slow-cooling process and should be used only when there is not time to anneal by slow cooling.

50. Hardening Carbon Tool Steels.—What has been said about heating for annealing applies also to heating for

hardening. After being heated to a temperature of from 50° to 100° F. above the upper limit of the transformation range, the steel is quenched immediately in a hardening solution. When quenched in brine or water, the steel will be very hard; when quenched in mineral oils, the steel will not be so hard; and when quenched in the other oils, mentioned in Art. **40,** the hardness will be intermediate between these two. The temperature to which the steel must be heated depends on the size of the work, other things being equal. For example, a very small tool, say one about $\frac{1}{4}$ inch in section, should not be heated more than 50° above the upper limit of the transformation range, or higher than about 1,400° F., while a larger tool, say one $\frac{7}{8}$ inch or larger in section, should be heated about 100° above the upper limit of the transformation range, or to about 1,450° F.

51. Tempering Carbon Tool Steels.—When tool steel is heated to the proper temperature and plunged into a hardening bath, the piece will be so hard that a file will not cut it. It will also be brittle. As practically all cutting tools must possess some toughness, it is necessary to reduce the hardness to suit the work expected of the tool, in order to increase the toughness of the metal. This is done by heating the steel to a suitable temperature after it has been hardened, and the operation is called tempering. The temper of the steel should be drawn immediately after the steel has been hardened in order to relieve the internal stresses that were set up in the steel by the hardening operation. If not tempered at once, there is danger of the steel cracking owing to these stresses. The heating is usually done in one of the tempering solutions mentioned in Art. **41,** the temperature of the bath being indicated by a thermometer. It is not necessary to quench the steel after it is brought up to the desired temperature.

52. Tempering by Color.—When the temper is being drawn by color, advantage is taken of the fact that as a piece of steel is heated, certain colors that appear successively on its surface serve to indicate its temperature. In order that the colors may be seen more readily, the steel is usually polished by rubbing it with a piece of sandstone, brick, or abrasive

wheel. These colors, which are commonly called *temper colors*, have nothing to do with the hardness of the metal but merely indicate the temperature to which it was last heated and this temperature determines the hardness. In Table II are given

TABLE II

TEMPER COLORS AND CORRESPONDING TEMPERATURES OF STEEL

Color	Temperature Degrees F.	Kind of Tool
Very pale yellow....	430	Scrapers, light turning tools, lancets
Pale yellow.........	450	Razors, surgical instruments
Medium yellow, or light straw........	460	Lathe tools, milling cutters
Full yellow, or straw	470	Penknives, drills for iron and steel
Brown.............	490	Taps, reamers, dies for screw cutting, small cutlery, shears, flat drills
Brown, with purple spots.............	510	Axes, planes, pocket knives, wood chisels
Purple.............	530	Twist drills, cold chisels for very light work, table knives, large shears
Dark blue..........	550	Wood saws
Full blue...........	560	Stone-cutting chisels, fine saws, daggers
Medium blue.......	580	Carving knives
Light blue..........	600	Drills for wood, cold chisels, swords
Gray...............	700 to 750	

the temper colors and their approximate temperatures, together with the drawing temperatures suitable for different kinds of tools.

53. Hardening and Tempering in One Heat.—Tools whose cutting edges only need be hard are frequently hardened and tempered in one heat. The best method, however, is to cool the steel that is being hardened and then draw the temper. If it is required to harden and temper the cutting edge of an ordinary lathe turning tool in one heat, the cutting end is first heated to the proper temperature, letting the heating extend pretty far back from the point. The tool is then plunged into cold water, chilling it about $1\frac{1}{2}$ inches back from the point. In plunging a tool in this way, it must be moved up and down a little to avoid starting a crack between the hardened part and the soft stock. After being chilled, the point is polished quickly. The heat retained in the stock will gradually run to the point and draw the temper. The colors are now watched as they appear on the polished surface. When the desired color appears at the cutting edge, the tool is at once dipped into water to prevent further drawing of the temper.

54. Pack-Hardening Tool Steel.—The pack-hardening process is used to prevent the fire from reducing the carbon in the surface of high-carbon steel. In this process, iron boxes are used and the work is packed in charred leather, granulated charcoal, or sometimes a mixture of one or both of these with charred hoofs and horns. Care must be taken to see that no piece of steel is near the walls of the box; ordinarily, they should be kept at least an inch away. The box is closed with a cover that is sealed with fireclay. After the clay used in sealing the cover has dried, the box is placed in a suitable furnace and held there a sufficient length of time to bring the entire contents of the box to the required temperature; that is, from 1,400° to 1,475° F.

55. In the pack-hardening process, it is necessary to know when the box has been heated throughout. A pyrometer may be used to determine the temperature of the furnace, and the desired temperature may be maintained until the work is heated throughout; or, *telltales* may be used to determine when the box has been heated throughout. The telltales consist of a number of $\frac{3}{16}$-inch wires extending from the top to the bottom

of the box through $\frac{1}{4}$-inch holes in the cover. If, after the box has been in the furnace some time, one of these wires is of an even red throughout when withdrawn, the box is left in the fire another hour or so; the time necessary for the best results can be determined by experiment. Great care must be taken during this heat to be sure that the temperature of the furnace is not allowed to rise above the required degree. If the first telltale piece withdrawn does not show the desired temperature, others must be withdrawn at intervals of 10 or 15 minutes, until the desired temperature is indicated; the timing should begin from this point. When the heating is complete, the box is removed, the cover taken off, and the pieces removed and quenched.

EXAMPLES OF HARDENING AND TEMPERING

56. Hardening Taps and Reamers.—With the development of modern manufactures, the making of taps and reamers has become a specialty, and tools of this class that are made in the tool room are frequently hardened by the toolmaker himself, who uses a suitable gas, oil, or electric furnace. For heating this class of tools, several methods are in use. Sometimes they are heated in a tube or a muffle in an ordinary forge fire or in a specially constructed coke furnace. In many cases it is best to allow the temperature of the furnace to fall somewhat below that required before introducing the tool and then, as the steel absorbs heat from the furnace, to increase the temperature until the required point is reached. In all of these methods the steel should be heated as rapidly as is consistent with safety, so as to avoid any chance of reducing the carbon in the surface. Taps and reamers are also frequently heated in a lead pot heated by gas or solid fuel. The principal objection to this method is that particles of lead sometimes adhere to the taps, especially in the case of square thread taps, and their presence will cause soft places in the tool. After being heated, the cutting parts of the taps or reamers are quenched in water.

57. Tempering Taps and Reamers.—After the pieces have been hardened, they may be tempered by being placed

in a bath of oil and bringing the oil to about 490° F.; or, they may be polished and tempered by being heated over a fire, a gas flame, a hot metal plate, or in hot sand until a brown color appears. When tempered in this way, it is advisable to heat the shank of the tool first, because such heating will tend to soften the core of the cutting section. The shank can be heated conveniently by rolling it over a hot metal plate.

58. Straightening Taps and Reamers.—During the hardening process, taps and reamers are frequently sprung out of true, and they are sometimes straightened by pressure after being heated to a temperature somewhat lower than that at which they are to be drawn. The heating may be done in a bath of hot oil, but some toolmakers claim that better results are obtained by the following method: The tap is placed between the centers of a lathe with the high side toward the tool post. The end of a bar of iron, clamped in the tool post, is brought to bear against the high side of the tap, which is then covered with lard oil and heated by a Bunsen burner until the oil begins to smoke. The tool post is then run forwards, bringing the bar of iron against the high side of the tap and springing it straight, or even bending it slightly in the opposite direction. The tap is then chilled by pouring water over it, when it will be found to be straight or only slightly bowed. As a rule, the toolsmith does not have the use of a lathe. In this case, the tap may be straightened by heating it to the proper temperature over a fire, over a flame, or in oil, and then striking it a few blows with a hammer, while held between blocks of hardwood. After the tap is straightened, the temper is drawn in the usual way to the desired color or to the desired temperature in oil.

59. Hardening and Tempering Twist Drills.—Twist drills may be heated in an oil or a gas furnace similar to the one shown in Fig. 2, or an electric furnace may be employed, but the lead bath is very commonly used for this purpose, especially for short drills. The temperature of the lead is kept between 1,400° and 1,450° F. In all such heating operations, it is well to exclude the daylight as far as possible, and to use as few

incandescent lights as will enable one to work. Under such conditions, the temperature can be judged very closely and the eye must always be depended on to some extent, even when pyrometers or heat gauges are used.

60. When a lead bath is employed, the surface of the lead should be covered to a depth of from 1 to $1\frac{1}{2}$ inches with powdered charcoal to exclude the air. Sometimes, in place of charcoal, a mixture of salt and potassium cyanide is used to top off the lead to protect it from oxidation. The smaller sizes of drills are frequently placed in clamps holding several, and all are dipped into the pot at once. Some manufacturers prefer to heat twist drills in muffles filled with charcoal, so as to avoid loss of carbon from the surface of the steel.

61. Short or standard-length twist drills will not spring much if dipped vertically into a suitable hardening bath, which is generally water or brine. The bath should be stirred in some way, usually by having a circulating pump attached, somewhat after the manner shown in Fig. 16. Very long twist drills show a tendency to spring when hardened; to overcome this tendency, the following method is sometimes used: The drill to be hardened is placed in a long pipe muffle, which is given a partial rotation every few seconds during the heating of the drill; this process insures uniform heating. The shank of the drill is next placed in an ordinary pneumatic drilling machine and rotated very rapidly. The drill is then lowered rapidly into the water, care being taken to keep it vertical. The rapid rotation of the drill tends to prevent the formation of steam pockets. When the drill is heated in a horizontal position, care must be taken to see that it is not bent in bringing it to a vertical position.

Twist drills are generally tempered in an oil bath, using a tempering furnace similar to the one shown in Fig. 10. The temperature of the bath is maintained at about 470° F.

62. Hardening and Tempering Milling Cutters. Milling cutters are preferably heated for hardening in an electric furnace or in a gas or an oil furnace similar to the one shown in Fig. 4. When the shop is not provided with any of these

furnaces, very successful work may be done with the aid of a lead bath, especially when a large number of small cutters are to be hardened. Good work may also be done in an ordinary fire, provided it is deep enough to insure freedom from oxidation by the blast. When heated in an open fire, the cutters should be turned frequently to secure uniform heating. Care must be taken not to overheat the edges, as, being thin, they heat more rapidly than the body of the cutter. The toolsmith should always be sparing with his blast, and should not economize too closely with his fuel.

63. After the milling cutter has been heated, it should be taken from the fire and plunged into the bath edgewise. In most cases the best plan will be to take it from the fire with the tongs, although it can often be removed with a hook. The hook should be used to lower it into the bath, as the tongs will prevent the bath from coming in contact with the steel at one point on each side of the body of the cutter and these points will harden after the balance of the cutter is hard, thus introducing serious stresses and usually warping, if not cracking, the piece. The hook, on the other hand, is in contact with but a line on the inside of the hole through the cutter and can have but little influence during the hardening. Milling cutters are usually hardened in clear water or in a brine solution.

64. When only a few cutters are made, they are usually tempered by being placed on a bar of metal heated to a dull red, the bar being at least $\frac{1}{8}$ inch smaller than the hole. The bar is rotated slowly, causing the cutters thereon to rotate and distributing the heat more uniformly. The cutters should previously be polished, so that the temper colors may be observed readily as they run from the hole outwards. When the proper color, usually a dark straw, appears at or near the points of the teeth, the cutter is dropped edgewise into a bath of cold water. The advantage of this method of tempering is that it produces a cutter having a tough center and tough metal around the roots of the teeth, while the points of the teeth are hard enough to do the work. Of course, each succeeding grinding of such a cutter will expose softer metal.

The smaller milling cutters, when made of carbon steel, are generally heated and hardened as just described and then tempered in oil. For small or delicate forms, this process gives even stronger teeth than the foregoing method, and cutters thus tempered possess the added advantage that successive grindings do not expose a softer metal.

65. End mills and shank mills are heated, hardened, and tempered in the same manner as taps, with the exception that the temper of a shank mill is sometimes drawn by placing the shank in a hot nut or ring and allowing the heat to run down the shank and out to the roots of the teeth. When the proper color appears on the teeth, the tool is quenched.

66. In hardening any milling cutter or hollow mill having a hole through it, provided the piece has not been annealed after drilling the hole, it should be removed from the fire when red hot and then allowed to cool slowly until the red has entirely disappeared, when it can again be placed in the fire, slowly heated to the required temperature, and plunged into a bath of lukewarm water or brine, working the piece around until it stops singing. It should next be plunged into a bath of oil, where it should be allowed to cool. Finally, the internal stresses should be removed by holding the cutter over the fire until it is warm enough to produce a snapping or sizzling noise when touched with a moistened finger.

67. Hardening and Tempering Plane Irons.—The irons for planing wood by hand, including the broad bits for jack-planes and jointers, as well as the narrower bits for molding planes, were formerly made by welding a tool-steel face to a piece of wrought iron. At present, such bits, or plane irons, are made of a fine quality of rolled or cast steel. The blanks are sheared or punched to the proper size, and any necessary machine work is done on them, including grinding the bevel. The cutting end of the bit is then heated to a cherry red by placing it in a lead bath. To insure heating to just the right distance from the cutting edge, the bits are held crosswise, in a special pair of tongs, in such a way that when the tongs rest on the edge of the crucible, or pot, the bits will extend into the

lead the correct distance. Several bits may be heated at one time; when taken from the lead, one at a time, they are dropped vertically into a tank of salt water or plunged with the tongs. The pieces are moved about rapidly until cool and then allowed to drop to the bottom of the tank. The bits fall into a wire basket, by which they can be lifted out when a sufficient number have accumulated.

68. The temper of plane irons is drawn between hot iron plates pressed together by a cam-motion hand press, which not only serves to bring the plates into contact with the plane iron, but also assists in flattening it. The temper is regulated by the length of time the bit is kept between the plates. Occasionally, one of the bits is tested for hardness with a file. It is claimed that greater uniformity of temper can be obtained with this test than by judging by color.

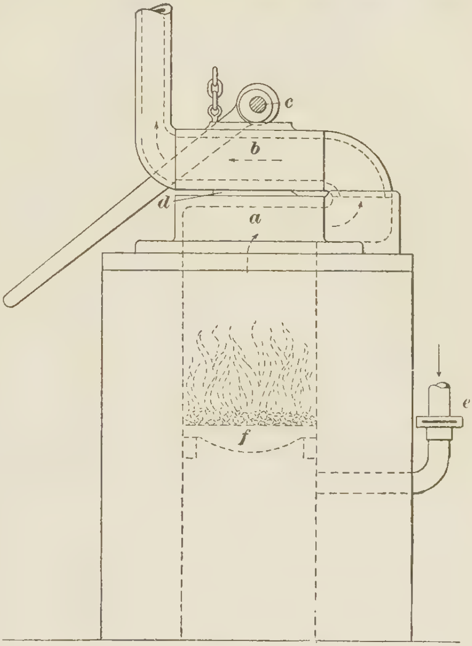


FIG. 19

69. The special furnace and clamping device for this work is shown in Fig. 19, some of the details being omitted to avoid complicating the sketch. The products of combustion from the coke or the hard-coal fire beneath pass through both plates *a* and *b* on their way to the chimney. The cam-shaft *c* is supported by brackets attached to the lower plate *a*, but not shown in the sketch. The upper block *b* is provided with a counterweight, so that it can be raised to put in the work.

The operation is as follows: The block *b* is raised, the piece *d* to be tempered is introduced and the block *b* is lowered and clamped firmly in place by means of the cam on the shaft *c*. After the work has been exposed to the heat a sufficient length of time, the block *b* is raised and the work removed. For maintaining the fire, a forced blast is used, the air supply being controlled by the valve *e* in the pipe through which the air is introduced below the grate *f*.

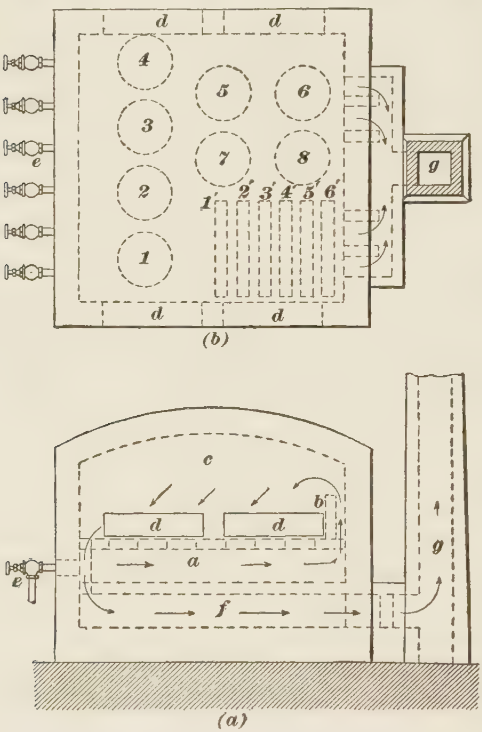


Fig. 20

70. Hardening and Tempering Circular Saws for Wood.—One of the best examples of hardening and tempering large flat work is that of circular saws for cutting wood. Such saws are hardened in the following manner: After the saw blank has been cut to shape and all preliminary machine work done on it, it is heated to a light cherry red on the flat bed of a large furnace. Two views of such a furnace are shown in Fig. 20, (*a*) being a side view and (*b*) a plan view. Several saws are placed in the furnace at one time, and they are frequently moved and turned to secure an even heating. They are introduced first at the coolest parts of the furnace and gradually moved to the hotter parts in the order shown in (*b*), *1* being the last saw to be placed in the furnace and *8* the first. A series of cross-cut

saws are also shown in (*b*); *1′*, *2′*, *3′*, *4′*, etc. indicate their successive positions in the furnace. The furnace is about 14 feet square and is heated by oil burners *e*, the flame from which passes through the flue *a* under the hearth, up over the bridge wall *b*, into the heating chamber *c*. It then passes down through openings in the hearth to a passage *f*, near the base of the furnace, that leads to the chimney *g*. Four large openings *d* are closed by firebrick-lined doors lifted by a hydraulic cylinder.

71. When the saw has reached the desired temperature, it is quickly removed from the furnace, placed in a vertical position in a supporting frame, and lowered edgewise into the hardening bath, which is generally composed of a mixture of whale oil, tallow, resin, and beeswax. After the saw is taken out of the bath, it is cleaned by scraping and then scoured with sawdust.

72. In drawing the temper, the hardened saw is placed between two flat, circular, cast-iron plates in a horizontal position, the upper plate weighing several tons and being lifted by means of a hydraulic cylinder. The reason for using such a heavy plate is to take out the buckling due to hardening and to give a uniform and close contact of the saw with the hot plates. The plates are kept evenly heated by revolving them in a furnace heated by a series of carefully controlled gas jets. The degree to which the temper is drawn is regulated by the length of time the saw is left between the plates, the hardness being tested with a file after removing the work from the plates. If the saw is too hard, it is returned to the plates. Saws for wood are drawn to a temper equivalent to a blue temper color, but usually in this method no attention whatever is paid to the color, the file test being used to determine their hardness.

73. Hardening and Tempering Cold Saws.—Cold saws are heated and nardened in the manner just described for wood saws, but sometimes the temper of the cold saw is not drawn at all, it being left just as it comes from the oil bath; at other times, the temper is drawn to a straw color, by means of heavy plates, as described in connection with wood saws.

74. Hardening and Tempering Dies.—Under the head of dies may be classified a great variety of tools, embracing all types from the heavy drop-hammer dies to the delicate and intricate punching and trimming dies for sheet-metal work. Drop-hammer dies are usually heated in a special furnace or face down in a coke fire, the face only being brought to the desired temperature. They are then hardened by being placed face down on suitable supports, with the face just below the surface of the hardening bath. The hardening solution is then forced against the face of the die in a series of powerful jets to prevent the formation of steam pockets and insure rapid cooling of the work. Sometimes the die is placed face up and subjected to the action of a series of jets of water. After hardening, the temper is drawn to the required degree by heating in an oil bath or over a fire or hot metal.

75. With thinner and more intricate press dies, greater care must be exercised in hardening and tempering. Usually these dies can best be heated in some form of oven furnace. If the die contains any screw holes or small holes that do not require hardening, they should be stopped with loose-fitting screws or asbestos meal, so as to avoid as far as possible the risk of cracking the die. The die may be hardened in water or in brine. Immediately after hardening, it should be removed from the bath and slightly warmed to avoid cracking. This reheating may be done by immersing the piece in boiling water or by holding the die over the fire until it is heated to such a temperature that a few drops of water sprinkled on it will immediately turn into steam. This temperature will not be sufficient to make the temper colors appear, but will aid in reducing the tendency of the die to crack.

76. A die made from a blank cut from a bar of steel and machined and worked out without annealing is likely to crack during the hardening process, especially when the die is of irregular outline. For this reason, the stock for dies should always be annealed when possible. If it is not possible to anneal the stock before the die is machined to shape, the

finished die should be heated to a uniform red heat, removed from the fire, and allowed to cool until black. It should then be reheated to the proper temperature and hardened.

77. The method to be used for drawing the temper of a die depends very largely on the form of the die and the use to which it is to be put. Cutting dies are drawn to colors ranging from straw to blue, depending on the work they are to perform. Sometimes, in the case of cutting dies, one of the dies is made much harder than the other, so that the harder die can be used to trim the softer one to exact form. This is an advantage when repairing the die to take up wear. After peening out the worn edge, the irregularities are removed by the harder die. The die on which the most work has been done should be the hard die, and the cheaper one, the soft die. Thus far no distinction has been made between the terms die and punch, the term die being used to cover both parts of the tools used for cutting and forming metal.

With forming, embossing, or coining dies, the temper is such that the metal is usually much harder than in the case of cutting dies, drawing dies sometimes being made as hard as possible.

78. Hardening and Tempering Flat Springs.—Under the head of flat springs may be included every variety from the small spring for locks and firearms to the heavy leaf springs for supporting locomotives. When of uniform thickness, the smaller springs are usually shaped from sheet metal of the required thickness. Sometimes the steel is annealed and bent to shape; but in other cases it is heated red hot and bent to shape, frequently by the use of dies. In the case of large tapered springs, the metal is either forged or rolled to shape. After the steel has been given the required taper, it is bent to a templet or is properly formed by the use of dies, when it is ready for hardening. As a rule, the steel will harden more uniformly if first annealed, which can be done by packing it in boxes with spent bone or a mixture of spent bone and charcoal, bringing it to the required heat in a furnace, and then allowing it to cool in the boxes. Sometimes large

springs are annealed by heating them separately in a suitable furnace and then placing them in a box of warm lime, where they are allowed to cool slowly.

79. Large springs are hardened separately; they are first heated to the required temperature and then cooled in a suitable bath. No universal rule can be given for the bath to be used, as it depends very largely on the character of the steel under treatment. For some steels, a bath of raw linseed oil is employed with great success, while some spring makers use a bath of fish oil. Sometimes it is better to harden in a brine solution, and at other times clear water will give the best results. Some brands of steel, especially the cheaper ones, require quenching in a bath of boiling water to secure the best results.

Large quantities of very small springs are frequently treated in bulk, being heated in some form of box or wire basket, either with or without packing material, and quenched by being dropped all together into the hardening bath.

80. After springs are hardened, they must be tempered. Tempering is done by several methods, one of which is to draw the temper in a saltpeter bath maintained at a temperature of 700° to 800° F. Large springs are very frequently drawn to color by polishing and then heating over a fire, a hot plate, or a sand bath. For most work they should be drawn to a full blue, sometimes to a very dark blue. Small springs are also frequently treated the same as large springs, except that the temper is drawn over a gas flame.

81. The temper of springs of fairly large dimensions is frequently drawn by a process known as **flashing off.** If linseed oil is heated to about 600° F., it will burn with a continuous white flame that can be blown out only with difficulty. If the temperature is slightly below this point, the vapor from the oil will burn if a piece of lighted paper is held over the oil bath, but will go out as soon as the lighted paper is removed. In tempering springs, advantage is taken of the fact that the point at which instantaneous flaming of the oil

occurs corresponds with the temperature to which the temper of the spring should be drawn.

82. The springs are first dipped into oil and then held over the fire, a flame, or a piece of hot iron, until the oil on the spring ignites. The spring is then plunged into a bath of oil for a moment to extinguish the flame and to cool the surface of the spring. By repeating this process several times, the spring is drawn to a uniform temper; flashing off three times is usually sufficient for any spring. If the oil were allowed to continue to burn on the surface of the spring, it would result in drawing the temper too far and in softening the spring to a degree at which it would lose its elasticity. Care must be taken to hold the spring far enough from the fire so that the oil will not ignite until the temperature of the spring has reached the temperature of the flashing point of the oil.

The temper of springs of small dimensions is frequently drawn by placing them in an oil or a salt bath and heating the bath to about 600° F.; for some work, a few degrees less is sufficient.

83. Hardening and Tempering Coiled Springs. Coiled springs may be made by taking high-temper wire, made especially for springs, and coiling it on a suitable mandrel in an engine lathe; these springs will frequently give good results, especially for tension springs. For compression springs, however, and especially for those of large dimensions, the metal is usually coiled while hot and is then hardened and tempered in much the same manner as flat springs, the heating being accomplished in a suitable furnace. The temper of large spiral springs is usually drawn by flashing off. If proper facilities are at hand, small springs are usually tempered by heating in an oil or a saltpeter bath.

HIGH-SPEED STEEL

84. Annealing High-Speed Steels.—High-speed steels are annealed by being heated to a temperature of about 1,500° F. and being cooled slowly. The heating for annealing is preferably done in an oven furnace or an electric furnace. The

cooling is done by shutting off the heat after the steel is heated throughout to the desired temperature and letting the steel cool in the furnace. Instead of cooling in the furnace, the tool may be withdrawn and buried in a generous quantity of sand, ashes, lime, or asbestos that has been previously heated and allowed to cool there. The usual precautions must, of course, be taken to secure a slightly reducing atmosphere during heating.

85. Heating High-Speed Steels for Hardening. For hardening, high-speed steels must be heated to a temperature near the melting point, about 2,200° F. The heating can be accomplished in a number of ways; but whatever method is used, it is essential that the steel be preheated slowly and uniformly to a temperature of about 1,500° F. The furnace in which this preliminary heating is done is usually spoken of as the *preheating furnace*. If this preheating is not done slowly and uniformly, the tool when finished will be likely to develop cracks.

Fig. 21

86. After being preheated to about 1,500° F., the steel should be brought rapidly to about 2,200° F. For this purpose, the pieces may be suspended in an oil or a gas furnace similar to that shown in Fig. 2, a special furnace capable of maintaining a very high temperature being used; or, they may be suspended in a crucible furnace, the crucible serving to protect the work from the flame and oxidation. A muffle furnace like the one shown in Fig. 4, the electric furnace, and the barium-chloride bath may also be used for heating. Great care must be taken to see that no air strikes the steel while it is being heated.

When the barium-chloride bath is used, the tools are placed in a wire basket, as shown in Fig. 21, or they are wired together and hung in the bath on a suitable hook. Tools with holes in them are easily handled by wire hooks. Neither the baskets nor the wires melt or burn away in the intense heat of the

bath, the barium chloride appearing to preserve the metal. The contact of the tools with one another does not prevent them from heating uniformly.

87. Cooling High-Speed Steels for Hardening. High-speed-steel tools are brought to white heat for hardening and are cooled in an air blast, an oil bath, or a lead bath. Whichever method is used, it is essential that the tools be brought quickly from the heating furnace to the cooling medium to prevent oxidation of the steel.

88. If cooled in an air blast, the tools will be somewhat oxidized. For this reason, air cooling is used only for such tools as are to be ground after hardening. This method is unsatisfactory for taps, reamers, and other tools machined to size. For air cooling, compressed air is preferable to that from a blower, owing to the higher pressure. The pressure must, however, be reduced to 2 or 3 pounds at the nozzle. To obtain uniformly good results, the air should be dry and cool. Passing the air into a large cylinder called a *separator*, causes the moisture to separate out and drop to the bottom. The dry air may then be piped from the top of the separator. Tools cooled in air are, as a rule, slightly softer than those cooled in oil.

89. An oil bath is perhaps the most commonly used cooling medium for hardening high-speed steels. It is necessary to provide some means of keeping the bath cool so that the heat of the steel will not cause a rapid increase in temperature; also, the oil bath should be located close to the heating furnace, so that there will be as little exposure to the air as possible when transferring the steel from the heating furnace to the bath. Any of the oils mentioned in Art. **40** may be used. Fish and cottonseed oils are perhaps the ones most generally employed. When fish oil is used, about 3 per cent. of heavy mineral oil may be added to suppress the offensive odor. In quenching, care should be taken to immerse the tool with its thinnest section in a vertical position, to prevent warping and cracking. A thin, flat die, for example, if quenched so that the flat face strikes the oil first would be warped and

rendered useless. After immersion, however, the tools may be turned to any convenient position. If it is of any considerable size, the tool must be kept moving in the bath so that all parts will be washed by cool oil, as otherwise the oil in contact with the steel will become so hot that proper hardening is prevented. When a number of small tools in a basket are heated for hardening in a barium-chloride bath, the entire basket of tools is quenched in the oil as if they were but one tool. After cooling, the barium chloride that adheres to the surface of the tools is removed with a wire brush. If the barium chloride should harden on the tool in sharp angles or slots, it can be softened by leaving the tool in boiling water for a few minutes.

90. A lead bath is also used to cool tools heated to a high temperature, though less commonly than the oil bath. The lead bath is maintained at a temperature of about 1,200° F., and the tools are quenched immediately after removal from the heating furnace. The bath should, of course, be located close to the heating furnace. After being cooled to the temperature of the lead bath, the tools may be removed and allowed to cool in the air or they may be cooled further in an oil bath.

When a lead bath is used to cool the tools, it is also used as a preheating furnace. No trouble is experienced by oxidation in removing the tools to the heating furnace from the lead bath, as the temperature of the steel is then a little below that at which oxidation would take place.

91. Tempering Tools of High-Speed Steel.—The temper of tools made of high-speed steel is generally drawn in an oil bath in the same manner as that of carbon-steel tools is drawn. As a rule, the temper of tools of high-speed steel is not drawn so far as that of carbon-steel tools. Roughing tools are left untempered. Ordinary milling cutters and similar tools are drawn to about 400° F. Large reamers and drills with heavy stocks are drawn to about 440° F. Ordinary drills, small reamers, and similar light-bodied tools that are subjected to twisting strains are drawn to about 460° F. Threading

dies and taps are drawn to about 490° F. Punches, stamping, or cutting dies and shear blades are drawn to about 530° F. Chisels and tools subjected to sudden shocks are drawn to about 570° F. Woodworking tools are drawn to temperatures ranging from 530° to 620° F., according to the shape of the tool and the kind of wood to be cut. Brass-working tools are drawn to temperatures from 40° to 60° F. lower than the temperatures to which the corresponding kinds of iron- and steel-working tools are drawn. The temper colors corresponding to the temperatures given are about the same as those corresponding to the same temperatures of carbon steels. For uniform results, however, it is better to depend on an oil bath, the temperature of which is shown by a thermometer, than to draw the temper by color.

92. Heat Treatment of Tools of Semi-High-Speed Steel.—The annealing, hardening, and tempering of tools made of semi-high-speed steel is done in the same way as that of tools made of high-speed steel, with the exception that, for hardening, the steels are heated to a lower temperature, namely, 1,800° to 2,000° F.

THEORY OF HEAT TREATMENT

CARBON STEEL

93. Allotropic Theory.—The various changes that take place in the structure and properties of steel during annealing, hardening, and tempering are due to physical changes, and not to any change in chemical composition. Any substance whose physical properties can be changed without any change in its chemical composition is said to be *allotropic;* and, by what is called the **allotropic theory,** the effect of heat treatment can be explained on the ground that steel is allotropic. The allotropic theory is sometimes referred to as the *beta-iron theory.* Other theories have been advanced to explain the changes that occur during heat treatment, but only the allotropic theory will be considered.

94. Iron, which is allotropic, exists in three distinct forms, known as *alpha iron*, *beta iron*, and *gamma iron*. **Alpha iron** is pure iron in the form in which it exists at temperatures lower than 1,382° F. **Beta iron** is the form in which pure iron exists at temperatures between 1,382° and 1,607° F. **Gamma iron** is the form in which pure iron exists at temperatures above 1,607° F. Beta iron and gamma iron, when present in steel, exist at other temperatures than those given, and under certain circumstances they may be obtained at ordinary atmospheric temperatures. Of the three forms, beta iron is the hardest. Gamma iron is softer than beta iron and alpha iron is still softer.

95. Annealed Carbon Steel.—If a piece of carbon steel is annealed, it will be affected in such a way as to form one or more of three substances, called *alpha ferrite*, *cementite*, and *pearlite*. Ferrite is pure iron and **alpha ferrite** is pure iron in the alpha form, that is, soft, tough, and ductile; hence, the effect of ferrite in tool steel is to decrease the cutting ability and to increase the toughness. **Cementite** is a compound of iron and carbon in certain proportions and is weak and brittle, but very hard. **Pearlite** is an intimate mixture of ferrite and cementite, and when viewed through a microscope it has the lustrous appearance of mother of pearl. The effect of pearlite is to give a fine crystalline structure to the steel, make it very strong, and render it much harder than ferrite. Carbon steel containing .85 per cent. of carbon, or the eutectoid, consists wholly of pearlite when annealed. The eutectoid is very hard, is very tough when annealed, and has the finest crystalline structure and the greatest strength of all forms of carbon steel. If carbon steel containing less than .85 per cent. of carbon is annealed, it will consist of pearlite and ferrite and will be tougher than the eutectoid, but not so hard. The amount of ferrite will increase and the amount of pearlite decrease as the percentage of carbon decreases. If carbon steel containing more than .85 per cent. of carbon is annealed, it will consist of pearlite and cementite and will be harder and more brittle than the eutectoid. The

pearlite will decrease and the cementite increase as the percentage of carbon increases.

96. Variations in Transformation Range.—If a piece of annealed steel consisting wholly of pearlite, that is, eutectoid steel, is heated to a temperature of about 1,355° F., a change in its structure and properties takes place. The alpha ferrite, or pure iron, forming part of the pearlite changes to beta iron and then to gamma iron, and the cementite forming the remainder of the steel goes into solution in the iron. This solution differs from a liquid solution, like salt in water, but it is a solution just the same. The resulting solid solution of carbon in gamma iron is known as **austenite** The change occurs at the point of decalescence. Heating beyond this temperature, 1,355° F., causes no change except to enlarge the crystals. If the steel is now allowed to cool, the temperature will fall to 1,250° F., the point of recalescence, at which point the gamma iron will change to beta iron and then to alpha iron without change of temperature; also, the alpha iron and the cementite crystallize out of solution, thereby forming pearlite.

97. If a piece of steel containing .10 per cent. of carbon is heated gradually, the point of decalescence is reached at 1,292° F. and the pearlite goes into solution in the iron. The temperature then rises to 1,380° F., at which point the alpha ferrite is transformed to beta ferrite while the temperature remains constant. The temperature then rises to about 1,606° F., at which point it remains while the beta ferrite changes to gamma ferrite. The resulting steel is austenite, or a solid solution of carbon in gamma iron. On cooling, the first change occurs at about 1,560° F., at which temperature the gamma ferrite becomes beta ferrite and the carbon is held in solution in beta iron. Then the temperature falls gradually to 1,380° F., where it again remains constant while the beta ferrite becomes alpha ferrite. The carbon is then in solution in alpha iron. As the temperature continues to fall, the ferrite crystallizes out little by little until a temperature of 1,250° F. is reached. This is the point of recalescence,

and the alpha ferrite and the carbon crystallize out in the form of pearlite. A brightening of the steel may be observed as this point is passed.

98. From the foregoing, it is concluded that the transformation range of steel containing .10 per cent. of carbon is from 1,250° to 1,606° F. Carbon steel with less than .10 per cent. of carbon has the same transformation range; carbon steel containing .30 per cent. of carbon changes to austenite, or a solution of carbon in gamma iron, at about 1,550° F.; and carbon steel with from .10 to .30 per cent. of carbon becomes austenite when heated to temperatures between 1,550° and 1,606° F. Therefore, the upper limit of the transformation range of carbon steel containing .30 per cent. or less of carbon is from 1,550° to 1,606° F. and the lower limit is 1,250° F. If carbon steel containing from .30 to .60 per cent. of carbon is subjected to heat treatment, it will act in much the same way as steel containing .30 per cent. of carbon. But instead of changing from alpha to beta and then to gamma iron at different temperatures, these changes are made at one temperature during heating; and during cooling the change from gamma to beta and then to alpha iron occurs at one temperature instead of at different temperatures. The upper limit of the transformation range varies, being about 1,550° F. for steel containing .30 per cent. of carbon, about 1,430° F. for steel containing .45 per cent. of carbon, and about 1,400° F. for steel containing .60 per cent. of carbon. Steel containing from .60 to .85 per cent. of carbon has the point of recalescence at 1,250° F. The upper limit of the transformation range varies, being 1,400° F. for steel containing .60 per cent. of carbon and 1,355° F. for steel containing .85 per cent. of carbon, that is, the eutectoid. If the steel contains more than .85 per cent. of carbon, the transformation range is the same as that of the eutectoid.

99. As previously explained, steels containing more than .85 per cent. of carbon, when annealed, consist of pearlite and cementite. The transformation ranges of these steels are the same as that of the eutectoid steel. All the cementite

does not, however, go into solution until the steel is heated to a temperature considerably higher than the upper limit of the transformation range. The temperature at which the cementite goes into solution for steel containing 1 per cent. of carbon is 1,440° F.; for steel containing 1.2 per cent. of carbon it is 1,602° F.; and for steel containing 1.3 per cent. of carbon it is 1,686° F. The point of recalescence occurs as before at 1,250° F. If steels containing more than .85 per cent. of carbon are heated to a temperature high enough for all the cementite to go into solution the steel structure will generally be rendered objectionably coarse.

100. Martensite, Troostite, and Sorbite.—On cooling steel rather slowly through the transformation range, the austenite changes first to *martensite*, then to *troostite*, then to *sorbite*, and finally to pearlite.

Martensite is chiefly a solid solution of carbon in beta iron, but an appreciable quantity of alpha iron is also present in it. When carbon steel containing less than 1.5 per cent. of carbon is heated above its transformation range and quenched in water at room temperature, martensite is formed. It is very hard, strong, and brittle. It is harder and more brittle than austenite, and is preeminently the constituent of hardened carbon tool steel.

Troostite is a mixture of carbon dissolved in beta iron, cementite, and alpha iron. It is softer and more ductile than martensite, and harder and less ductile than sorbite. It is largely found in tempered steels.

Sorbite is the connecting link between troostite and pearlite. It has more strength and hardness and less ductility than pearlite, but is softer and more ductile than troostite. Its constituents are identical with those of troostite; but it contains less hardening carbon, that is, carbon dissolved in beta iron.

101. Austenite.—Austenite is a solid solution of carbon in gamma iron, and experiment has shown that its properties are the same as those of gamma iron. Thus far it has been considered to exist only at high temperatures, that is, at temperatures above that at which the gamma iron changes

to beta iron on cooling. Under favorable conditions, austenite may be had in steels at low temperatures. For example, it may be had by quenching in ice-cold water carbon steel having not less than 1.5 per cent. of carbon from a temperature above the upper limit of its transformation range. To retain austenite at low temperatures, the iron, when cooling, must be kept from changing to the beta or alpha form and the carbon must be retained in solution. Austenite is never produced at atmospheric temperatures in the commercial heat treatment of ordinary carbon steels.

102. Effect of Carbon in Steel.—One effect of carbon as a constituent of steel is to retard the change from austenite to pearlite during cooling. This change occurs in the following order: Austenite to martensite; martensite to troostite; troostite to sorbite; and sorbite to pearlite. The presence of carbon hinders these changes, and thus makes it possible to obtain a desired structure by quenching at the correct temperature; whereas, if these changes occurred rapidly, it would be impossible to quench the steel at the exact moment required. The carbon also prevents the martensite, troostite, or sorbite from changing to any other form at atmospheric temperatures. No other element in steel will accomplish this result. The greater the amount of carbon in the steel, the greater will be the amount of beta iron that can be retained in that form at low temperatures, and, as a result, the harder can the steel be made.

103. Summary of Heat Treatment of Carbon Steels. When steel is to be annealed or hardened, it must be heated to a temperature above the upper limit of its transformation range. For convenience of reference, the upper limits of the transformation ranges of carbon steels of different compositions and other information are grouped together in Table III.

ALLOY STEEL

104. Tungsten and Molybdenum Steels.—Tungsten and molybdenum have the same effect as constituents of steel, but 2 per cent. of tungsten is required to produce the

same effect as 1 per cent. of molybdenum. Tungsten in steel results in the formation of a double carbide of iron and tungsten very much like cementite. It goes into solution at a temperature of from 2,200° to 2,400° F., this point being the upper limit of the transformation range for tungsten steel. If the steel contains less than .6 per cent. of carbon and less than 7 per cent. of tungsten, it will have a pearlitic structure when cooled slowly; that is, it will be soft and ductile. But if either the carbon or the tungsten content is increased, the structure will be cementitic; that is, it will contain carbide particles. If cooled rapidly from a temperature above the transformation range, martensite will be obtained at atmospheric temperature. It retains this structure very well, even when reheated, as the martensite does not begin to change to troostite until a temperature of 1,100° F., which is a red heat, is reached. Tungsten is the constituent of most high-speed steels.

105. Chrome Steel.—If a steel containing less than 5 per cent. of chromium is cooled slowly, the structure will be pearlitic. The effect of chromium is to increase the hardening power of the steel, but the hardness produced is different from that produced by carbon, because the steel is not rendered so brittle. Thus, by reducing the carbon and increasing the chromium content, hardness combined with toughness may be obtained. Chromium has little effect on the transformation range of steel.

106. Vanadium Steel.—Vanadium in quantities up to .5 per cent. is often found in steel. This element has no marked effect on the transformation range, and steel containing it becomes pearlitic when cooled slowly. Its principal effects are to make the steel ductile and springy. It also intensifies the influence of the other constituents; that is, it makes their influence more apparent.

107. High-Speed Steel.—High-speed steel is an alloy of iron, carbon, and chromium with either tungsten or molybdenum, and sometimes it contains vanadium also. The carbon content varies from .6 to .8 per cent., the tungsten from 12 to

20 per cent., and the chromium from 2 to 5 per cent. The vanadium content is usually less than .5 per cent., and if the tungsten is replaced by molybdenum, from 6 to 10 per cent. of the latter is used. The properties of high-speed steel are a combination of the properties of tungsten and chrome steels. If cooled slowly, the steel becomes pearlite; but if cooled rapidly from a temperature above 2,200° to 2,400° F., the upper limit of the transformation range, martensite is formed as in the case of tungsten steel. The martensite thus formed is very stable and the steel may be reheated to a red heat, or about 1,100° F., before the martensite will change to troostite. Because of this fact, high-speed steel is said to have the property of *red hardness*, or hardness at a red heat. The chromium in the steel gives hardness combined with toughness, and the carbon is necessary to produce martensite. Vanadium serves to intensify the effects of the other elements.

108. Semi-High-Speed Steel.—The class of steel known as semi-high-speed steel has the same constituents as high-speed steel, but the percentages of tungsten and chromium are lower. Its properties are intermediate between carbon tool steel and high-speed steel. The upper limit of its transformation range varies from 1,800° to 2,000° F., according to its composition. It becomes pearlitic when cooled slowly, but martensitic when cooled rapidly from a temperature above its transformation range. It does not possess the property of red hardness, but it will stand more reheating than carbon tool steel before it changes to troostite.

109. Steel Structure and Heat Treatment.—Carbon steel, as previously explained, is merely an alloy of iron and carbon. By heat treatment, however, the steel is transformed from one of its many possible structures to another, as, for example, from pearlite to martensite, from martensite to troostite, etc. As a rule, though not always, any of these steel structures can be had at atmospheric temperatures. Austenite, however, is normally stable only at high temperatures, while pearlite is the normal steel structure at low temperatures. When it is desired to make steel as hard as it is possible

to make it, the steel structure must be transformed into martensite. To make steel as soft as possible, the steel structure must be made pearlitic. When some hardness is to be sacrificed to secure toughness, the steel structure is made troostitic. Sorbite is the steel structure obtained by air annealing.

HEAT TREATMENT OF LOW-CARBON STEEL

ANNEALING, OIL TREATING, AND CASE HARDENING

CLASSIFICATION

1. Steel is usually divided into two classes, high-carbon and low-carbon steel. The heat treatment of high-carbon, or tool, steel has been considered in *Hardening and Tempering*. Low-carbon steel generally contains from .1 to .5 per cent. of carbon, and sometimes as high as .75 per cent. The treatment of low-carbon steel may be divided into the treatment of those steels that are composed principally of carbon and iron, and those that contain, in addition to these substances, one or more other substances, such as nickel, chromium, and vanadium. Those steels that are composed principally of iron and carbon are commonly spoken of as **carbon steels**; those that contain one or more substances in addition to iron and carbon are called **alloy steels.**

2. Low-carbon steels may be subjected to various heat treatments, to impart certain desired qualities to them. They may be annealed to make them soft and to relieve the internal stresses; they may be tempered in oil, or oil treated, to make them tough and to increase their strength, or they may be case hardened to give them hard surfaces. It is often desirable that the outer surface of low-carbon steel be hardened. To do this,

carbon is added to the outer surface by a heat-treating operation carried on in the presence of carbon; this operation is known as **case carburizing.** The hardening of a surface thus treated is known as **case hardening.** The combined operations of case carburizing and case hardening are often spoken of simply as case hardening.

CARBON STEELS

ANNEALING

3. Effect.—Annealing has a double object: first, to effect a change in the size of the crystals of the steel; and second, to remove the internal stresses due to forging and irregular cooling. In order to effect a change in the character of the crystals of the steel, it is necessary that the steel be heated above the transformation range and then cooled suddenly. By transformation range is meant the range of temperature between the point of recalescence, 1,250° F., and the point at which the necessary changes occur to give the best annealing and hardening results. The upper limit of the transformation range for .10-per-cent. carbon steel is about 1,606° F.; for .30-per-cent. carbon steel, about 1,550° F.; for .45-per-cent. carbon steel, about 1,430° F.; and for .60-per-cent. carbon steel, about 1,400° F. In order to remove internal stresses, it is not always necessary to heat to the point of recalescence, as such stresses are frequently due to a partial hardening of the steel, in which case the heating of the piece to from 800° F. to 900° F. will usually cause the desired change in structure. The forging temperature for low-carbon steel is from 1,800° F. to 2,000° F. When the steel at this temperature is taken from the furnace and placed under the hammer or forging press, it immediately begins to cool and crystallize. Working on the piece retards and disturbs this crystallization; and as the work usually proceeds from one end of the piece to the other, the result is that the finished forging is very irregular in its crystallization and the metal is subject to serious stresses whose exact nature is

unknown, but which may amount to several thousand pounds per square inch. It is to remove the stresses from irregular crystallization that forgings should be annealed by heating above the transformation range; annealing the forging at any lower temperature will not effect this result. In pieces heated

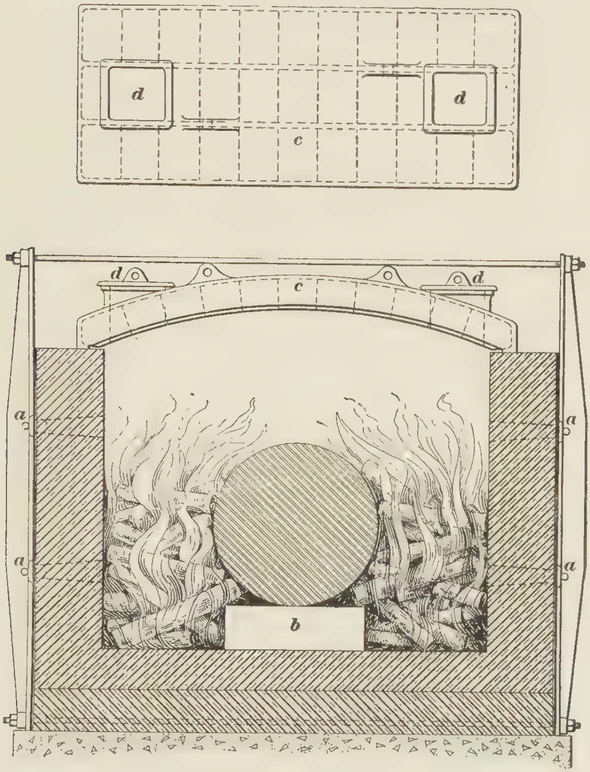


FIG. 1

to the transformation range and then suddenly cooled, there may be present stresses due to a partial hardening of the steel and these may be removed by reheating to a lower temperature.

4. **Annealing Furnaces.**—The furnaces used for annealing are of the same form as those described in *Hardening and Tempering*, and the same furnace may generally be used for

either hardening or annealing. For annealing large pieces, specially constructed furnaces are, however, necessary, as the temperature must be carefully controlled. In Fig. 1, a cross-section of a **wood-burning furnace** for annealing large shafts is shown. This furnace is equipped with peep holes *a* on one or both sides through which the temperature may be measured

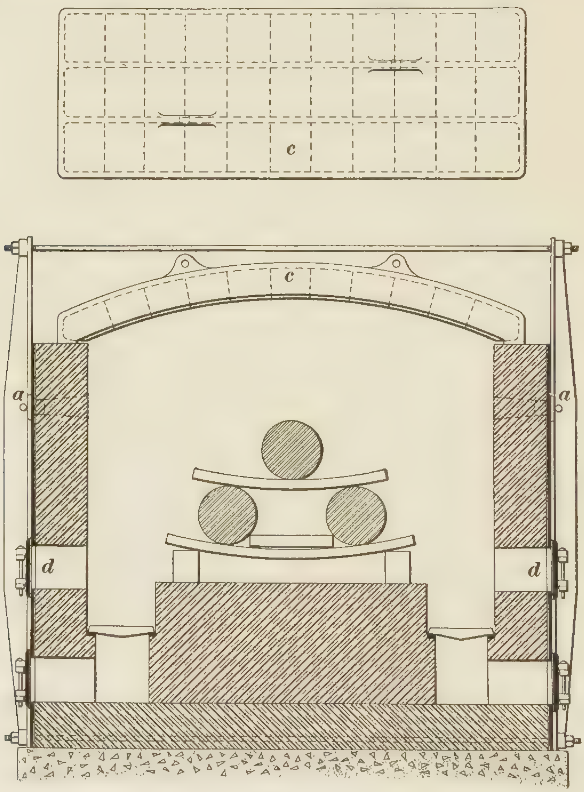


Fig. 2

with a pyrometer, or estimated with the eye. Suitable piers *b* are provided, on which the shaft is supported, and the top of the furnace is covered with cast-iron frames *c* that are lined with firebrick. Openings are also provided at *d*, through which the fire may be observed and fresh fuel added. These furnaces are sometimes more than 100 feet long.

5. A **coal- and wood-burning furnace**, constructed for annealing long work, is shown in Fig. 2. This furnace is so constructed that it can be heated with either wood or coal, or with both. It is provided with peep holes *a* through which the temperature of the work may be observed, or measured with a pyrometer, and the roof, or top, of the furnace is closed with bungs *c*. The fire-doors *d* are located along its sides, and the fire may be made at any point, or all along the furnace. As shown, the furnace has been charged with three shafts that are supported on cast-iron bars.

6. A cross-section of an **oil-burning furnace** especially constructed for annealing large links, or eyebars, is shown in Fig. 3. This furnace is constructed entirely below the floor

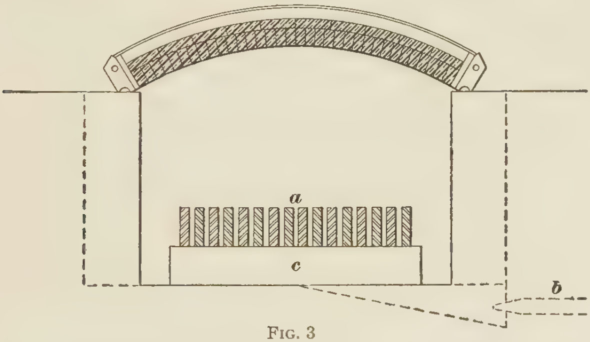


FIG. 3

level, with the exception of the arched top, or cover. The top is made in sections, so that it can be lifted off, and is lined with firebrick. The eyebars *a* are made of steel and have a large eye on each end. The forging of these ends produces internal stresses in the pieces, and hence the whole link must be carefully annealed. The bars *a* are placed in the annealing furnace as soon as the eyes are completed and while they are still hot, the supports *c* being so arranged that the ends of the bars with the eyes will overhang. When the furnace is full of work, the top is put on and the oil burners *b*, placed at regular intervals along the entire length of the furnace, are lighted. The eyebars are then heated to a medium red heat, when the oil is shut off and the furnace allowed to cool slowly for about 17 hours.

The top is then removed and the work taken out. Furnaces similar to the one shown in Fig. 3, but heated by gas, are also in common use. They are made in different sizes, suitable for all sizes of work. Shafts and hollow forgings are sometimes heated in a vertical position in gas-heated pit furnaces.

7. Heating and Cooling for Annealing.—The first step in annealing carbon steel is to heat it from 50° to 100° F. above its transformation range. When heated to this temperature, no matter what their previous arrangement may have been, the steel particles are as fine as it is possible to get them. Should the steel be heated to a point below its transformation range, the annealing would not be effective; and if heated considerably above the transformation range, the particles would become coarse and continue to grow coarser while cooling. To anneal carbon steel, then, the steel should be heated to a temperature just beyond the transformation range, and maintained at that heat until it is heated throughout to that temperature. After heating the steel throughout to the proper temperature, it is cooled in the air, in the furnace, or in packing material as explained in *Hardening and Tempering*.

OIL TREATING

8. The strength of steel seems to depend very largely on the sizes of the individual crystals thereof; the finer the crystals, the stronger is the steel. What is known as **oil treating** is frequently resorted to in order that the crystals may be as fine as possible. This treatment consists in heating the steel to a point slightly above the transformation range and then plunging it into a bath of oil. This preserves the amorphous condition of the steel that results from heating it above the transformation range. The sudden chilling of the steel, however, results in a certain degree of hardening, and hence it is usually necessary to anneal oil-treated forgings, or to draw the temper by heating them carefully to from 800° F. to 900° F. When an extensive line of tools or machinery is to be manufactured from low-carbon steel, great care should be taken to obtain metal of a

uniform character, and to determine, by experiment, the best temperatures for treating it. In the case of very large forgings, it is possible to take pieces from the forging and analyze and test them carefully, but in the case of small work it is impossible to test each piece, and hence the necessity for always using steel of uniform composition. For oil treating small forgings of a regular shape, special cast-iron chairs, or supporting frames, may be made to support a number of pieces while heating, and then these frames with the pieces may be lowered into the oil bath and all cooled together. Such a method as this effects great economy in handling.

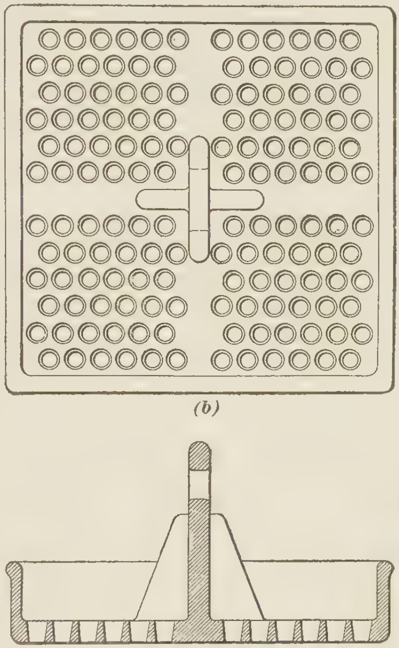


Fig. 4

9. Small pieces may be treated by placing a number in a cast-iron tray like that shown in Fig. 4 and heating them to the proper temperature. They are then taken out and lowered into a tank of oil until nearly cold, but lifted out while still hot enough to drain and dry quickly. The tray shown in Fig. 4 is 26 inches

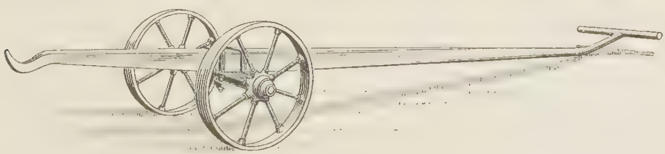


Fig. 5

square; (*a*) is a section, and (*b*) a plan view. The bottom of the tray is $1\frac{1}{2}$ inches thick, and has a number of holes, $1\frac{1}{2}$ inches

in diameter, through it. There is a heavy lug in the center, with a hole to receive the crane hook or other lifting device.

For lifting and moving the cast-iron trays from the furnace, a special lifting hook of the form shown in Fig. 5 may be used. The cast-iron box or tray containing the work is brought from the furnace with the lifting hook and set on the floor near the oil tank. A crane is then used to place the tray in the bath of oil.

CASE HARDENING

10. Methods.—Owing to the fact that the percentage of carbon in low-carbon steel and wrought iron is small, they cannot be hardened sufficiently to resist any considerable wear, unless they are case hardened. The case hardening adds carbon to the outer surface of soft, or low-carbon, steel or wrought iron, thereby converting the surface into high-carbon steel, which may be hardened. The three methods commonly used to case harden are, *hardening by packing*, *hardening in cyanide*, and *hardening by gas*. The cyanide used may be either potassium cyanide or potassium ferrocyanide.

11. When **case hardening by packing,** the steel or iron is heated to about 1,700° F. while in contact with wood or bone charcoal, ground bone, charred leather, carbonate of potash, or other material rich in carbon, the metal absorbing carbon from the material in which it is packed and heated. The depth to which the carbon penetrates depends on the kind of packing used, the temperature at which the metal is kept, and the length of time the metal is heated in it. The higher the temperature, the more rapid is the absorption of carbon; while the longer the heat is maintained, the greater is the depth to which the carbon penetrates. The absorption of carbon produces an outer layer, or surface coating, of high-carbon steel that becomes hard when the piece is cooled suddenly, thereby imparting to the metal the desired wear-resisting quality while retaining the toughness of the soft core of unchanged iron or low-carbon steel. When the depth of the hardened surface is to be comparatively deep, the hardening is done by packing.

12. The most common *packing materials* for case hardening are ground bone, either raw or charred, charcoal, charred leather, or charred hoofs and horns. Each material is especially advantageous for some purpose. It is advisable, however, to use packing materials containing but a small percentage of elements that might be injurious to the steel, as, for instance, sulphur and phosphorus.

For hardening small, delicate work, the following mixture has been recommended: Equal parts of bone charcoal and

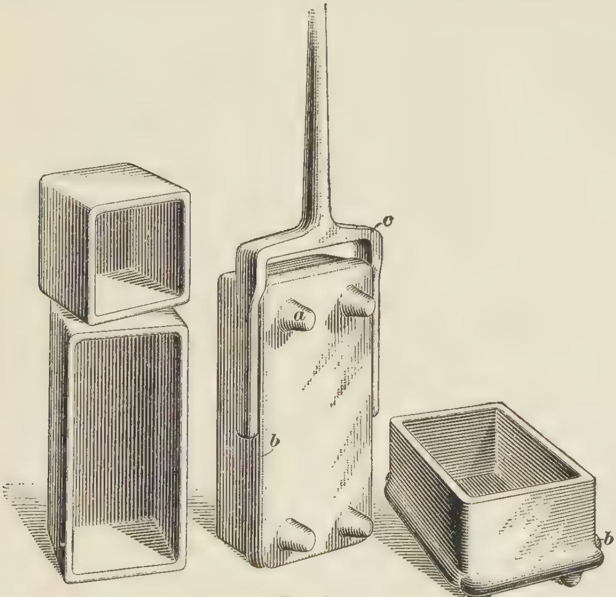


Fig. 6

granulated hardwood charcoal are thoroughly mixed together, and with each twenty parts of this mixture is thoroughly mixed one part of charred leather.

High, quick heats will not leave a piece of case-hardened work as strong as it would be if a lower heat had been used while it was being carburized, provided that in all cases the heat is sufficiently high for carburization. Extremely high heats should be avoided, especially when the work is taken from the case-hardening boxes and quenched immediately.

13. The *case-hardening boxes*, or *pots*, used are generally of cast iron, and are of various forms and sizes. Several boxes of very good design, especially for small work, are shown in Fig. 6. They are made with legs *a* a little over 1 inch high so that the flame will circulate under as well as over the box, and heat it uniformly. The boxes illustrated have a rib *b* around the lower edge to engage a fork *c* that is used to handle them. Large boxes are seldom made with a rib, but are handled with tongs or with some form of fork that passes under the bottom of the box. For ordinary work, the boxes vary from about 4 inches square by 4 inches deep, up to 12 in. × 14 in. × 16 in., though for special work they are frequently made 12 or 14 inches wide and deep by $4\frac{1}{2}$ feet long. Wrought-iron or steel boxes made of $\frac{1}{2}$-inch iron or steel plate flanged at the corners and riveted together are sometimes used. Case-hardening boxes are also made of special forms to suit certain kinds of work that is hardened in large quantities. One type of these special boxes is shown in Fig. 7. The box shown is suitable for work of an annular, or ring, form, such as bevel gears that have large openings in their centers. The advantages of using this type of box are that less packing material is required, and, as the heat passes up through the internal opening, the work is more uniformly and quickly heated.

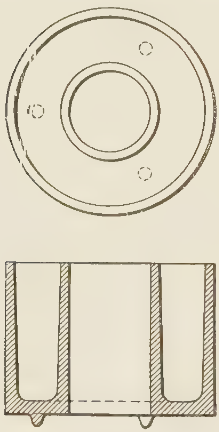


FIG. 7

14. To judge the condition inside of the case-hardening or annealing box, *telltales*, or *indicators*, are often used. These are pieces of wire introduced through holes drilled in the top of the box and allowed to extend through the bone, between the work, clear to the bottom of the box. These pieces of wire should project from the top 1 inch or so, and when the box has been in the furnace some time one piece is withdrawn, and if it shows a uniform red throughout, the work is timed from this point. If the middle of the wire is still black or dull red,

another is drawn later, and this operation is repeated until the interior of the box is found to be of the desired color. After having tested the different-sized boxes in this way a few times, the operator will be able to judge the time correctly. Sometimes the telltale is used also to judge the depth of case hardening; in such a case, it should be a rod about $\frac{1}{4}$ inch in diameter and made of the same kind of steel that is to be case hardened. The rod should be withdrawn quickly, quenched in water, and then broken to observe the depth to which the work has been hardened, which will be shown by the depth of a band of finer crystalline structure.

15. Small pieces of steel made from low-carbon steel, such as gun and typewriter parts, are frequently given a hard surface to resist wear by **case hardening in cyanide.** When but a thin film of hardened steel is required, or when localized case hardening is necessary, this method may be used. The pieces to be hardened are dipped into a bath of molten potassium cyanide and left until they have attained the temperature of the bath. The cyanide is decomposed and the carbon enters the surface of the steel or iron, thus carburizing it. After the pieces have absorbed the desired amount of carbon, they are removed and dipped into a suitable hardening bath; cold water is generally employed for this purpose. If too hard, the temper can be drawn just as in the case of ordinary carbon steel.

16. Potassium cyanide causes the steel to scale when it is plunged into the bath, leaving a clean surface, so that the steel hardens very quickly. Because of its scaling effect, potassium cyanide is not considered as good as potassium ferrocyanide, called also prussiate of potash, for case-hardening work having sharp corners. The prussiate of potash forms a scale that does not allow the water to act as quickly as it otherwise would, thus protecting the steel when it is first plunged into the bath; the prussiate of potash forms slight deposits in corners at the roots of teeth, and thus protects them from the first influence of the cooling bath.

17. *As potassium cyanide is extremely poisonous, great care must be taken in handling it;* the absorption of a very small

quantity through cuts in the hands may have a fatal effect; in fact, lump cyanide should be handled with the bare hands just as little as possible. After melting the cyanide, care should be taken not to inhale the fumes, as they are extremely poisonous, and not to allow any of the hot material from the bath to be thrown or splashed on the operator, as it will cause serious and painful burns.

18. Case hardening by gas is a process in which the carbon is added to the steel by heating the steel to the required temperature in the presence of a gas containing carbon. The advantage of this method is that the case hardening can be done more rapidly, more uniformly, and to a greater depth than is possible by packing in solid materials containing carbon or by the use of the cyanide process. The exposed surfaces of cavities are readily carburized by the gas, as it circulates about them freely. When packed in materials composed of solid carbon, the carbon gradually leaves the packing material and soon becomes ash; consequently, the steel cannot then be further carburized in it. With the gas process, however, volatile carbon is always present. A complete plant for case hardening by gas consists of a generator of carburizing gas and the machine in which the carburizing is done. When gas having the desired composition is available, the generator may be dispensed with. Many gases have been experimented with for use in this process, and the gas to be employed is specified by the maker of the carburizing machine used. A neutral gas may be made in a producer and passed through a scrubber to remove grit and dirt, after which it is passed through a generator supplied with refined petroleum. In passing through the generator, the gas takes up volatile carbon from the oil. The mixture is then conveyed to the carburizing machine, where it is heated in the presence of the materials to be case hardened.

19. Case-Hardening Furnaces.—Furnaces for case hardening may be divided into those suitable for *hardening by packing* and those for *hardening in cyanide*. Furnaces suitable for hardening by packing are made to receive the case-hardening boxes, or pots, in which the work to be case hardened is

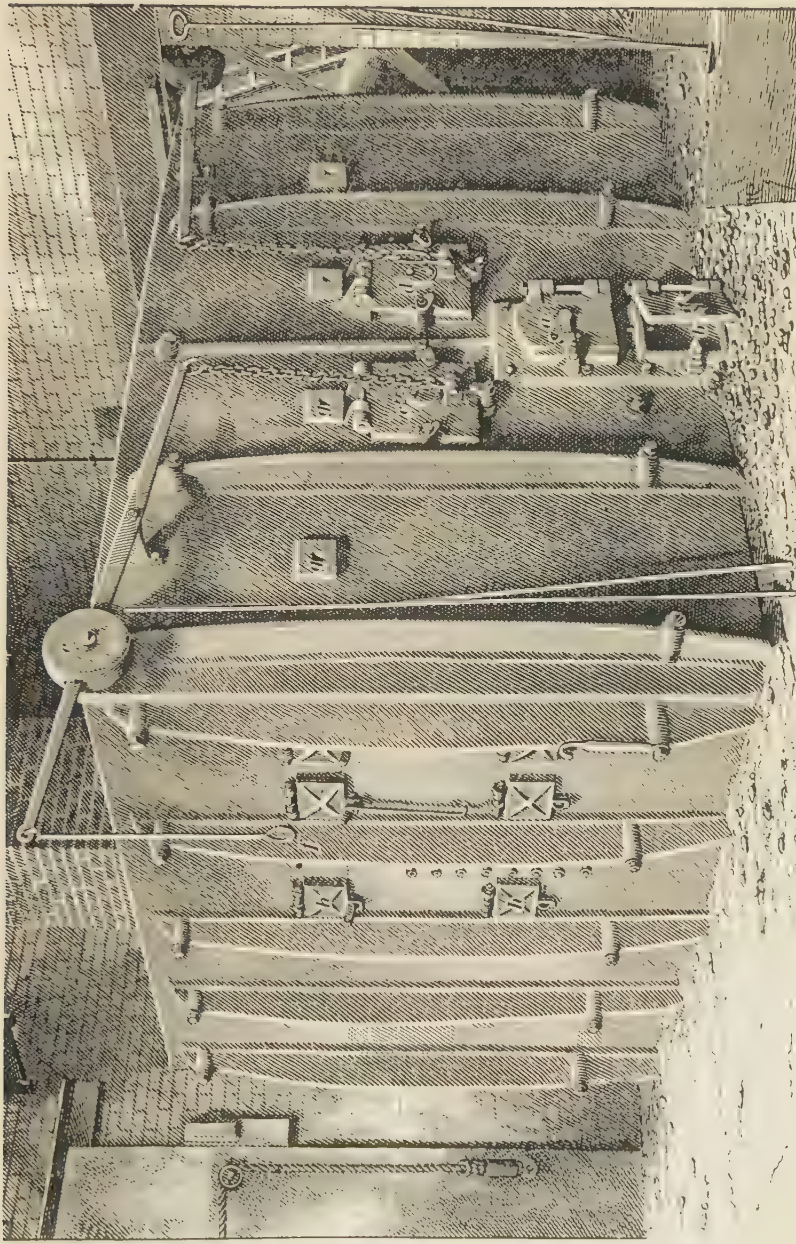


Fig. 8

packed. Furnaces for hardening in cyanide contain pots that hold the molten cyanide in which the work is dipped.

20. Furnaces for hardening by packing may be subdivided according to the kind of fuel they burn; as, for example, coke-burning, oil-burning, and gas-burning furnaces.

21. An outside view of a large *coke-burning furnace*, suitable for hardening by packing, is shown in Fig. 8, and a conventional cross-section of the same furnace is given in Fig. 9. The furnace contains a muffle, that is, a chamber in which the products of combustion do not enter and in which the work to be heated is placed, and is incased in heavy cast-iron plates. The fire-door of the furnace is shown at *a*, Fig. 8, the ash-pit door at *b*, and the entrances to the muffle are at *c* and *d*. The doors *c* and *d* are counterbalanced by the weights *e*, and their movement is controlled by handles *f*. Peep holes *g* are arranged at the front of the furnace, while doors *h* in the side are used both to observe the temperature of the muffle and to clean the passages. The fire-place of the furnace is so arranged that the products of combustion will circulate about the muffle and keep it at a uniform temperature. Coke is used for the fuel because it does not give off soot or clog up the passages. The muffle used is large; it is made of fireclay tile and is laid with fireclay mortar. About 2 weeks' firing is required to get this furnace hot all through and ready for the case-hardening operation. The furnace illustrated is intended to be used where large work

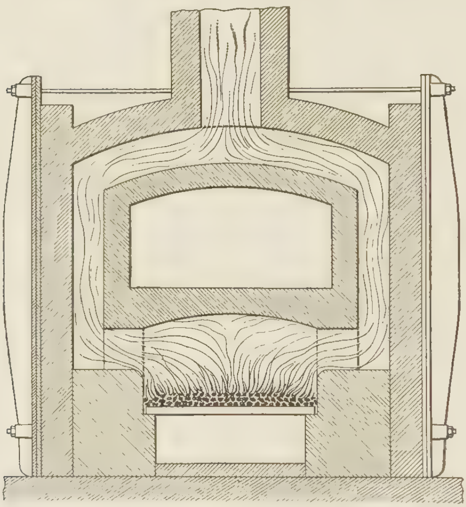


FIG. 9

or large quantities of small work is done. It gives excellent results, but is only applicable where the amount of work is sufficient to keep the furnace in continuous operation.

22. In shops where large engines are built, the wristpins and crankpins are frequently case hardened, so as to reduce wear as much as possible; there are also many other large pins

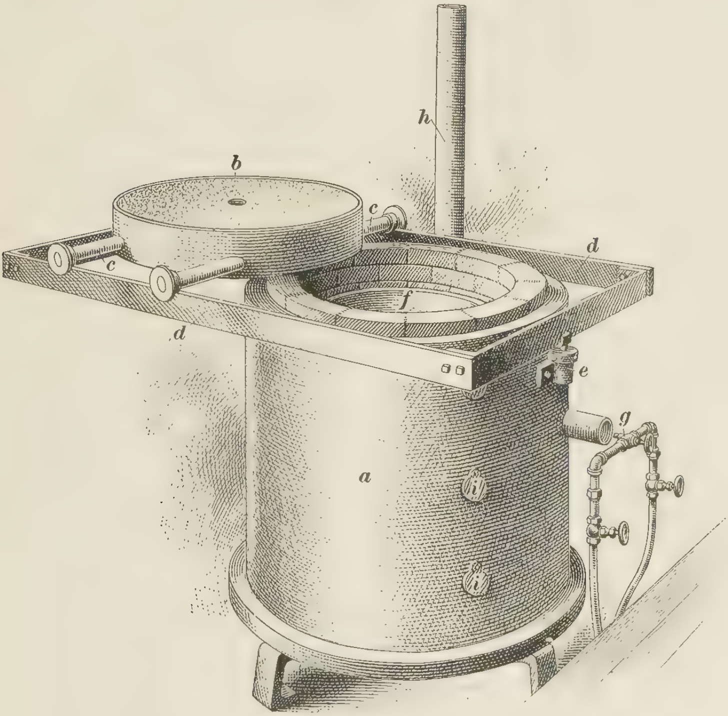


FIG. 10

or short shafts that may be case hardened to advantage. Work of this character can be hardened best in a vertical position; this necessitates the construction of a special case-hardening furnace, together with special pots and lifting devices. An *oil-burning furnace* for this class of work is shown in perspective in Fig. 10 and in cross-section in Fig. 11. It has a cast-iron shell *a*, $1\frac{3}{8}$ inches thick, 42 inches outside diameter, and 41 inches

high, a firebrick lining $4\frac{1}{2}$ inches thick, and a clay bottom covered with firebrick. The cover *b* is a ring casting 6 inches high, having pins or projections cast on the inside to hold the fireclay filling in place; it is supported by four arms *c*, at the outer end of each of which is a roller that runs on the steel tracks *d*. The frame supporting the tracks *d* can be adjusted, by a screw at *e*, so that the cover just clears the furnace. The pot *f* is lowered into the furnace by a special three-pronged lifting device shown in Fig. 12. The three hooks at the end

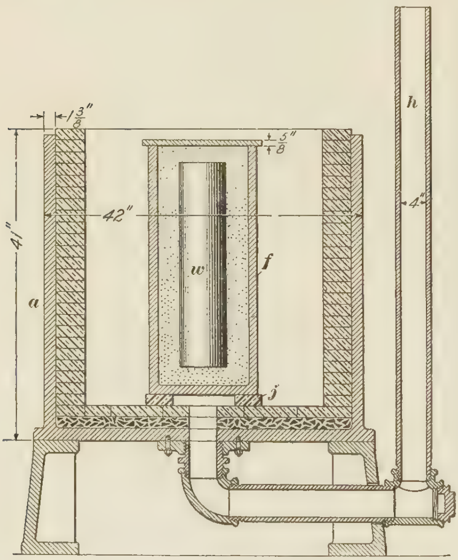


Fig. 11

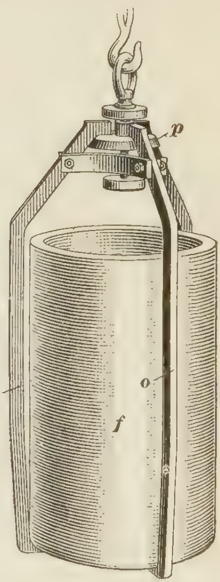


Fig. 12

of the prongs *o* are forced under the bottom of the pot by the conical piece *p* attached to the lifting device at the top, as shown. The pots are 16 inches inside diameter and are 30 inches high. They are covered with a round plate luted on with fireclay. Only one piece of work *w*, Fig. 11, is placed in the pot at a time. The work is surrounded by several inches of granulated bone or other packing mixture. The furnace is heated by a crude-oil burner *g*, Fig. 10, the flame from which circulates around the pot. The pot stands on three firebricks *j*, Fig. 11; beneath

it an opening connects with a pipe h, passing under the furnace and up one side; this pipe should extend 3 or 4 feet above the top of the furnace, and serves to carry off the smoke and gases. The first heating of large pins is sometimes continued for 40 hours. To enable the workman to observe the temperature

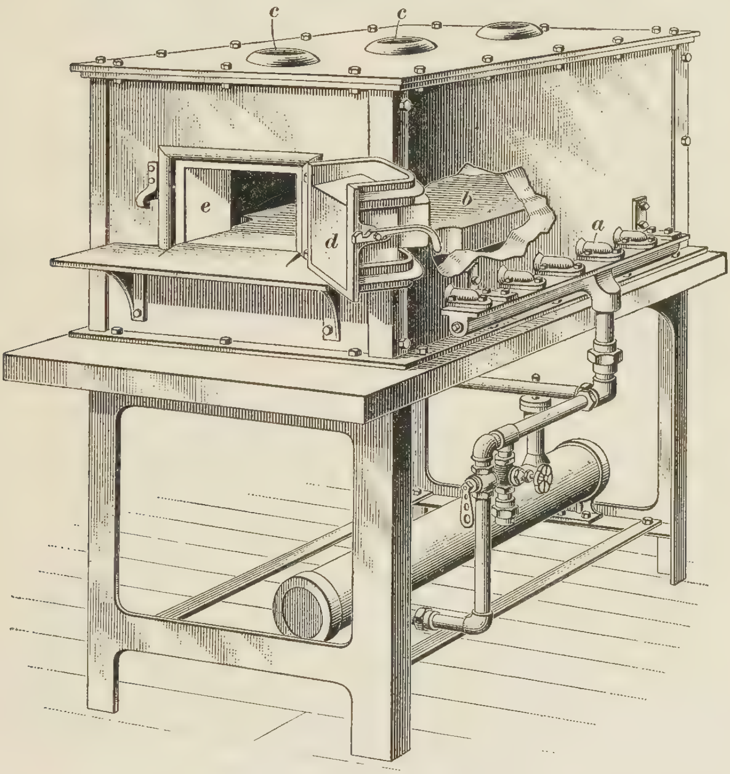


FIG. 13

of the pot, peep holes are provided in the side of the furnace, as shown at i. When an extra depth of case hardening is desired, the work is left in the pot in the furnace 24 hours, then allowed to cool, removed, and repacked in fresh material. It is then returned to the furnace for another 24 hours' heating.

23. When a moderately small amount of case hardening is to be done, a *gas-burning furnace* of the form shown in Fig. 13

will be found very useful. This furnace has a series of gas burners *a*, arranged along each side, below the bottom plate *b* of the oven. The products of combustion rise around the outer edges of this plate, on which the case-hardening box containing the work is placed, and escape through the openings *c*. The opening *e* is closed with a fire-clay plug *d*, supported in the door.

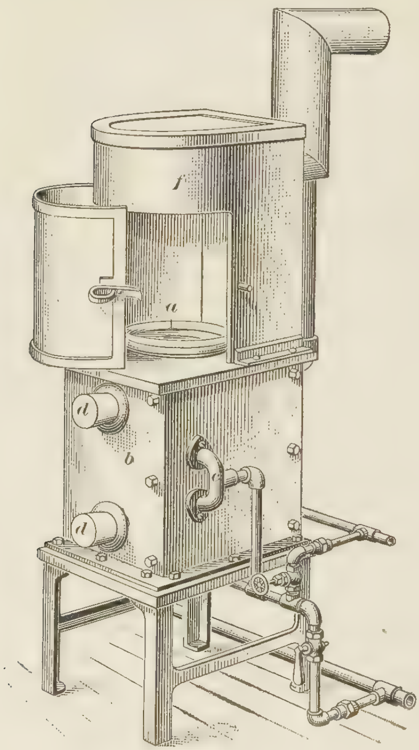


Fig. 14

24. When the work is to be case hardened in cyanide, the pot containing the cyanide may be heated in an ordinary forge, but it is better to heat it in a regular **cyanide-hardening furnace.** In Fig. 14, one form of gas-burning, cyanide-hardening furnace is shown. The cyanide pot *a* is located in the heating chamber *b*, which is heated by gas burners *c* on each side of the furnace. The holes closed by the blocks *d* are for lighting the gas or for observing the temperature of the pot. The hood *f* is placed over the furnace so that the fumes will be carried up the chimney.

25. Cooling Baths for Case-Hardening.—If a large amount of case-hardening work is to be done, some special form of cooling bath, for use either with oil or water, is necessary. The most important requisite is that provision should be made for maintaining the bath at the desired temperature. Two styles of cooling baths for use with different classes of work

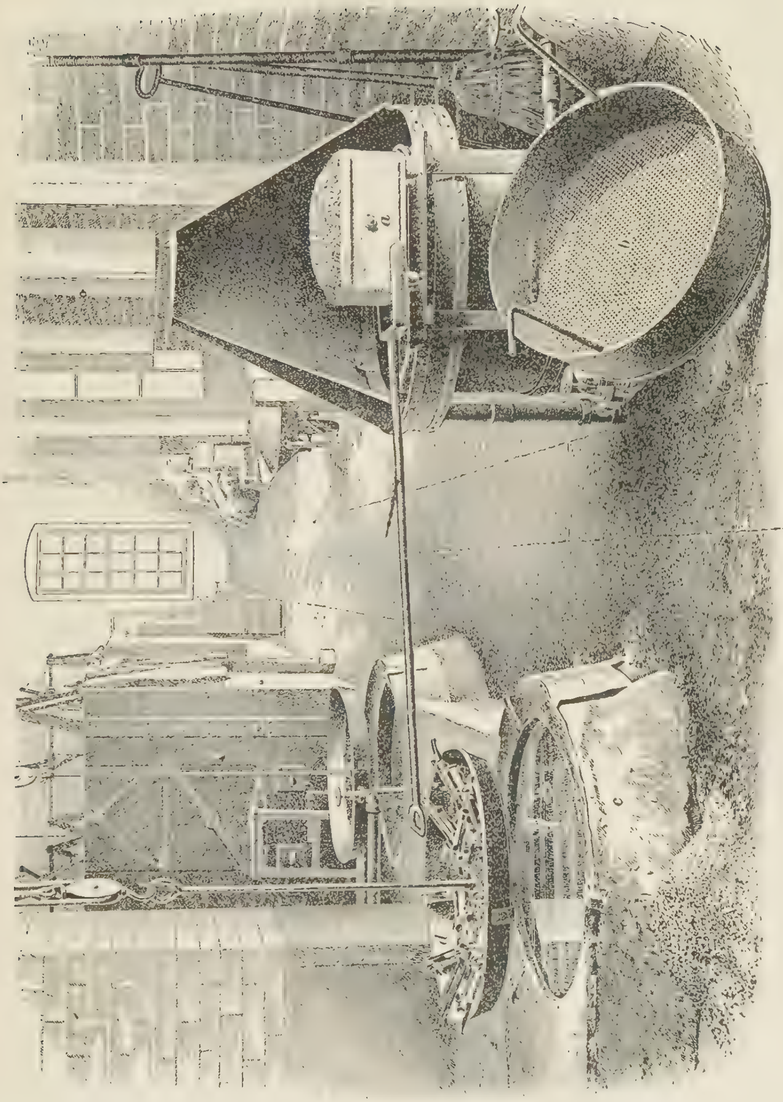


FIG. 15

are shown in Fig. 15. That on the right consists of a cylindrical tank of water about 30 inches in diameter, surrounded by a water-jacket in which a good circulation is maintained to keep the bath at the desired temperature. The work is brought from the furnace in the packing box *a*, placed at the side of the tank, and inverted in such a way as to pour the work and packing material in a continuous stream into the water. The work collects in a sieve *b* suspended in the tank, while the packing material passes through to the bottom of the tank, from which it is removed periodically. A hood is arranged over the tank to protect the workman from the steam and fumes that rise as the work is poured into the tank. This method of cooling will produce a very pretty mottled appearance on the work.

26. Large work that requires surface hardening without the mottled appearance and at the same time must be extremely tough, is frequently hardened in a tank like that shown at *c*, Fig. 15. This is an oil tank 30 inches in diameter, surrounded by a water-jacket through which the water is constantly circulating to maintain the desired temperature of the bath. The case-hardening pot is brought from the furnace and placed by the side of the bath; the work is removed one piece at a time, dropped into the bath, and collects on the pan *d*, which is suspended in the oil. When all the work has been hardened, the pan is raised from the bath with a suitable hoist, and the work allowed to drain. This method of cooling produces a fairly hard surface and a dark-blue color, the work being hardened so that it is very tough. After the pieces have drained for some time, they are removed and cleaned with sawdust. The finish left by this method of hardening is one that resists rust very well.

27. For cooling crankpins and wristpins, the device shown in Fig. 16 is used. It consists of an outer casing *b*, within which is a 10-inch pipe *a* perforated with $\frac{3}{16}$-inch holes placed $2\frac{1}{2}$ inches apart. The outer pipe *b* is provided with an opening *c* through which water is supplied by a hose attached to a hydrant. The whole device is supported on bars *d* placed across the top of

a water tank. The work *e* is lifted from the case-hardening pot by an eyebolt, as shown. It is then lowered into the cooling case and the water turned on. The water passes through the perforated holes, striking every part of the surface. The waste water flows through the opening in the bottom into the water tank.

28. Temperature for Case Hardening.—For best results when case hardening, the work should be heated to a temperature of from 1,650° to 1,750° F., 1,650° to 1,700° F. being preferred, and kept at that temperature until it has been carburized to the desired depth. The temperature can be found best by the use of pyrometers, but when no pyrometers are available the temperature can be estimated with the eye, as a temperature of 1,650° F. corresponds to a salmon heat and a temperature of 1,725° F. to an orange heat.

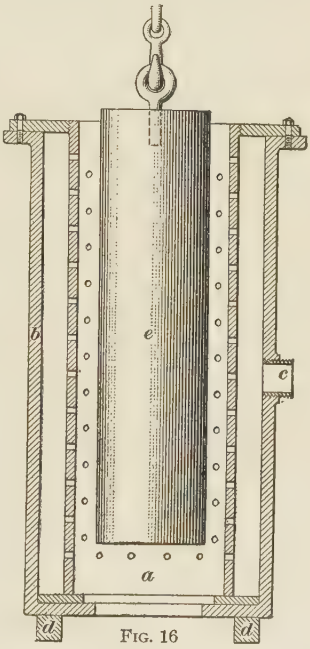


FIG. 16

29. Examples of Case Hardening by Packing.—Various kinds of work are often case hardened by **carburizing in ground bone** and then reheating to a temperature higher than the upper limit of the transformation range, that is, from about 1,400° to 1,450° F., and plunging into a bath of cold water or brine. When it is desired to produce a hard surface on the work, rather than a mottled appearance or certain special colors, the work may be packed in granulated raw bone in suitable boxes, first placing in the bottom of the box a layer of bone at least two-thirds as thick as the work. For instance, for screws $\frac{3}{4}$ inch in diameter and smaller, a $\frac{1}{2}$-inch layer of granulated bone should be put in the bottom of the box, and on this

alternate layers of the work and bone, care being taken that no two pieces touch each other and that none comes within $\frac{1}{2}$ inch of the sides of the box. When the box is filled to within $1\frac{1}{2}$ inches of the top, it should be given a thin layer of raw bone, and the balance of the space filled with bone that has been used; the cover should then be put on and luted with clay. After the luting has had time to dry, the box should be put into a furnace and heated for from 3 to 4 hours, for work of the size mentioned, provided that it is packed in moderately small boxes, as, for instance, boxes measuring 4 in. $\times$ 4 in. $\times$ 8 in. on the inside.

30. In heating any work for case hardening, it is necessary to use a box proportioned to the size of the work, for if very small work is packed in a large box, it will take several hours for the heat to penetrate to the center of the box; and as a consequence the work around the outside of the box may be case hardened very deeply, while that in the center has had practically no opportunity to absorb carbon, and hence will be soft. If it is necessary to pack small work in a large box, it should be placed around the outside of the box and a layer of bone put between the work and the walls of the box, and then several rows of the work surrounded by raw bone, the center of the box being filled with spent, or old, bone.

31. After the box has been heated a sufficient length of time, the entire contents may be thrown into clear, cold, soft water. Delicate pieces should be dropped into oil. The tank into which the work is thrown should be of sufficient depth to insure the thorough cooling of the work before it reaches the bottom.

32. To case harden pieces of steel 3 inches or more in diameter or thickness, the work may be surrounded by at least $1\frac{1}{2}$ to 3 inches of raw bone and heated to a bright orange, 1,725° F., for 18 hours; it should then be plunged into cold, running water or into salt water. Large work of this kind is usually removed from the packing box and plunged separately, while in the case of small work the entire contents of the box are dumped into the hardening bath. When an extra

depth of case hardening is required, the pieces may be heated, as already mentioned, and allowed to cool in the box; they should then be removed, repacked in fresh bone, and heated again as before, and then plunged into cold water.

33. When a fine-grained, hard surface is required, the work is sometimes carburized and allowed to cool in the packing box. It is then reheated carefully to the lowest temperature at which it will harden properly when plunged into the cooling bath. This has the effect of refining the steel, as in the case of high-carbon steel. The temperature at which the steel absorbs carbon in the case-hardening box is usually well above the temperature at which the carburized steel should be hardened. If the steel is hardened at the temperature at which it is carburized, the surface will have a rather coarse crystalline structure; hence, it must be reheated to a lower temperature to obtain a fine-grained, hard surface.

34. Special care is required in case hardening large, flat pieces to prevent them from warping. Disks 2 feet in diameter and 4 inches thick should be packed in round boxes that hold one disk each. The work may be placed, flat side down, on a carefully leveled bed of 4 or 5 inches of the best granulated bone, and should have at least 4 inches of the bone packed on top and around it. Some steel workers prefer to place a thin layer of charred leather next to the work to prevent scaling, but this is not necessary. After packing, the cover should be luted on, and the box heated to a temperature of from 1,650° to 1,750° F. for from 8 to 10 hours from the time the box is thoroughly heated. After the box has been removed from the furnace, the pieces should be taken out and placed edgewise in the hardening bath, which should be large enough to chill the work quickly and should be provided with a supply of flowing water. In case hardening large, flat pieces, there are four points to be observed: first, plenty of bone should be used; second, the pieces should be heated to from 1,650° to 1,750° F.; third, the pieces should be dipped edgewise into the cooling bath; and fourth, plenty of water should be used and the water should be kept agitated.

35. After emptying the case-hardening pots into the cooling bath, the bone may be separated from the work and thoroughly dried. As long as it is black after use, it still contains carbon, and hence can be used again, though it is best to mix the old bone with some new. About one part of new bone to two parts of old is a common mixture; as the new granulated bone is white, and the old, partly burned bone is black, the mixture of the two will result in a gray color. For small work, a dull gray, that is, two or three parts of old bone to one of raw bone, may be used. For larger work, a light gray should be used, sometimes containing equal parts of old and new bone, and sometimes less than half old bone. A little experience will indicate the proper proportion of old and new bone to use for this work. Constant burning will finally reduce the bone to a white ash that is valueless for case hardening. As a rule, the bone is used until it begins to look gray, then it is discarded for case hardening, but is used for packing work for annealing.

36. Good results may also be obtained by **carburizing in carbonate of potash.** This material is frequently used when the work to be case hardened is heated in the type of furnace shown in Fig. 8. The muffles of the furnace are charged with a mixture in about the proportion of 25 pounds carbonate of potash, 30 pounds bone black, and from 160 to 200 pounds of charcoal. The potash and bone black are first mixed thoroughly together, and the resulting mixture is thoroughly mixed with the charcoal. The charcoal should be in pieces the size of walnuts, and the potash like granulated salt, and not lumpy. This mixture will last about 2 weeks, when it should be taken out of the muffle and a new charge put in. None of the old mixture should be returned to the furnace, as it loses strength when exposed to the air. The articles to be case hardened are buried in the hot mixture, and should be entirely covered in the muffle. The muffle door should be kept closed except when changing or inspecting the work. The time that the work is left in the muffle depends on its size and the depth of case hardening desired. Small work requires 3 or 4 hours for hardening to a moderate depth, while large work or heavy

articles require 24 hours. Locomotive links should be left in the muffle from 12 to 14 hours, and guide bars from 18 to 24 hours.

37. A blackboard should be placed near the furnace with suitable headings painted in white; opposite these, the order numbers, names of the pieces, and time they were put in and the time they are to be taken out should be recorded with chalk. The pieces are removed from the muffle one at a time and quickly plunged into clear, cold water. The cooling bath should be deep enough to permit the longest piece to be plunged endwise. It is a good plan to place a sample piece of iron or steel in the muffle with the work. This may be removed, quenched, and broken, so as to note the depth to which the case hardening has penetrated.

38. Examples of Case Hardening in Cyanide.—As a rule, dies, cutting tools, engravers' plates, etc. hardened in potassium cyanide must be heated somewhat longer than pieces that are simply hardened to obtain a surface that will resist wear. The temperature of the cyanide bath is usually from 1,650° to 1,750° F. Ordinarily, from 3 to 5 minutes is a sufficient length of time to leave a piece in the cyanide. Some classes of work are hardened by cooling in lard oil. One method especially useful in hardening steel that requires a fairly hard surface, but may require some straightening, as, for instance, plates for steel engravings, is to heat in the cyanide and then cool in lard oil to a temperature of about 525° F., and then allow the piece to cool in water. This treatment will case harden the steel quite thoroughly, yet will leave it in such a condition that it can be straightened.

39. Gun parts that require a mottled blue surface that will be hard enough to resist wear fairly well are sometimes case hardened by placing them on a hook on the end of a steel rod and dipping them into molten potassium cyanide for about 2 minutes, or until they are at an orange heat. They are then quenched in water, giving them a jerky, up-and-down motion, the first dip carrying them barely under the surface, and each succeeding one deeper. This results in an irregular cooling,

accompanied by slight oxidation of the surface, which gives the desired mottled effect. The cooling, however, should be sufficiently quick and uniform to prevent setting up serious internal stresses in the metal.

40. It is occasionally desirable to harden a part in cyanide after it has been previously carburized in a packing material and annealed. This is sometimes done in the case hardening of small gears for automobiles. After the carburizing in the packing material is completed, the structure of the interior of the part may be too coarse for the purpose for which it is to be used, and a sharp division between the carburized and uncarburized portions is noticeable when a specimen is broken and examined. When the work is annealed after the carburizing, the interior structure becomes much finer, and some of the carbon in the outer surface may penetrate deeper into the part. In order to supply more carbon to the outer surface, the part is then carburized further in cyanide, the carburizing sometimes being repeated.

41. Localized Case Hardening.—Frequently, it is desirable to harden some parts of an object and leave the balance soft, as, for instance, to harden the centers at the ends of an arbor or a cutter bar; this may be accomplished by heating the piece to a dull red, applying dry potassium cyanide to the centers, returning the work to the fire, heating to an orange heat, and then cooling in water. When a center is to be hardened, it is best to take the piece with the tongs and plunge it into the bath with the center up, but with a jet of water from a tap or from a hose to play on the upper end of the arbor, so that the water will enter the center and harden it throughout. When the center is plunged down, the end of the arbor may be hardened somewhat, but a steam pocket generally forms in the center itself and prevents its hardening properly.

42. Frequently, case-hardened pieces of work have openings or projections that must be left soft for riveting, drilling, or for other operations. When this is the case, the work may be packed in the ordinary manner, heated for the proper length of time, and allowed to remain in the boxes until cool, as would

be done in annealing. When the work is removed from the boxes, its surface will be soft, though somewhat carburized, the depth of carburization depending on the time the steel remained in the furnace. The parts to be left soft must then have the outer surface removed by machining or filing, thus removing the portion of the steel containing carbon, and exposing the low-carbon steel which will not harden under subsequent treatment. The work should then be heated to the proper hardening temperature, and plunged into water, as in hardening tool steel. On removing the work from the bath, it will be found that the outer surfaces containing the carbon have been hardened, while portions from which the carburized outer surfaces were removed are soft and can be riveted or operated on in any manner desired. The same results may be obtained by covering the parts to be left soft with a coating of asbestos or fireclay before the steel is carburized.

43. The hardening may also be localized by first either copper- or nickel-plating the work, and then removing the copper or nickel from the portions to be hardened and leaving the plating on the portions that are to be soft, the plating serving to prevent the carbon from entering the steel where it is to be soft. The pieces are then packed in boxes and heated in the ordinary manner, and when plunged it will be found that the exposed parts are hard, while all parts protected by the plating are soft and can be machined as easily as before. When the finished parts only of a piece are to be case hardened, as, in the case of gears for automobiles, the work may be plated before machining, and as the machining operations will remove the plating from those parts only that are desired to be hardened, the work is ready for hardening, either by packing or in cyanide.

44. If, when work is packed in any material for case hardening, it is desired to make some spot extremely hard, a small piece of potassium cyanide or prussiate of potash may be put on that spot when packing the piece in the bone. A small iron spoon is used to handle the cyanide for this purpose.

45. Case Hardening for Colors.—By case hardening, a beautiful mottled appearance may be obtained on the work.

To obtain this mottled effect, the work, as well as the material in which it is packed, must be absolutely free from grease or oil. Charred bone is free from grease and is a good material to use for this purpose. Raw bone may be charred by putting it into boxes, say 9 in. × 9 in. × 36 in., covering the boxes and placing them in the furnace at night after the work is withdrawn. The heat remaining in the furnace will be sufficient to char the bone during the night. If there is much fire left, it will be necessary to draw part of it, as the object is simply to char the bone, but not to burn it, thereby eliminating all grease. If small boxes are used, they must be watched so that they may be removed just when the bone is all charred.

46. After a supply of charred bone or charred leather has been provided, the work should be packed in boxes, using this material just as the raw bone is used for packing ordinary work. The work should then be brought to a red heat and held there for from 2 to 4 hours. To get a good color, the heat must be held uniform; if the work is heated too hot there will be no color. A cherry-red heat gives good results, although with small work a somewhat lower temperature may give the desired results. In packing work to obtain colors, various mixtures of packing material are frequently used, as, for instance, charred bone and wood charcoal. Sometimes charred leather is mixed with one or both of the above ingredients. When case hardening for color, no attempt is made usually to harden the work to any great depth, the requirements being a hard but thin surface and a good color.

47. While good colors are sometimes obtained by quenching in rather hard water, it is nevertheless best to use soft water. Some provision should be made for circulating the water in the bath; this is usually accomplished by arranging the inlet pipe so that the water will be discharged upwards from the bottom of the tank in a series of jets. The inlet pipe may also be arranged so that the water will enter the bath at the bottom, where it is mixed with compressed air, which escapes upwards in a series of bubbles. A sieve, or grating, should be hung at such a distance from the top of the bath that the work will be

thoroughly chilled before it comes to rest on it, and the meshes of the sieve should be large enough to allow the burnt bone to pass to the bottom of the tank. It is absolutely necessary to have running water in the tank if large amounts of work are to be thrown into it. After the work has been thoroughly heated, the box is brought from the furnace to the bath, the cover removed, the box held close to the surface of the water, and the work poured in. This operation must be performed quickly and carefully to prevent the air from acting on the steel before it reaches the water. At the same time, with large boxes of work, care must be taken not to dump in the material as a solid mass, for, under such circumstances, much of the work would reach the sieve without being chilled, and hence would not be hardened to the desired degree.

48. The work is removed from the hardening bath by lifting out the sieve, or grating, on which it falls. It should next be dipped into clean, boiling water, after which it can be dried in sawdust. It should then be given a light coat of oil to bring out the colors and to prevent it from tarnishing.

USUAL HEAT TREATMENTS FOR CARBON STEELS

49. While any of the carbon steels may be annealed, oil treated, or case hardened, yet it frequently happens that a combination of the annealing, oil-treating, and case-hardening operations is necessary to obtain the desired properties in the steel. The heat treatments for the steels depend largely on the percentage of carbon contained in them. These treatments may be varied to suit the particular work to be done, and must often be modified as determined by trial.

In designating carbon steels, the amount of carbon in the steel is frequently indicated by the number representing the percentage. Thus, .10-per-cent. carbon steel is designated 10 carbon steel, .20-per-cent. carbon steel is designated 20 carbon, etc. They are read "point 10 carbon steel" and "point 20 carbon steel"; also, "10 point carbon steel" and "20 point carbon steel," etc.

50. .10 Carbon Steel.—About the only effect produced on .10 carbon steel by heat treatment is to increase its toughness a little. This treatment consists of heating the steel to about 1,500° F. and quenching in oil or water. As .10 carbon steel, in the annealed state, tears badly in turning, threading, and other machining operations, it should be heat treated before being machined. This steel may be case hardened, but it is not as good for this purpose as .20 carbon steel.

51. .20 Carbon Steel.—The effects of heat treating .20 carbon steel are to increase its toughness materially and its strength a little, and to refine the grain after forging. This is done by heating to about 1,500° F. and quenching in oil.

The most important use of .20 carbon steel is for parts that are to be case hardened. When these are not to carry much load, or withstand shocks, but must be hard on the surface, they may be carburized at a temperature of from 1,650° to 1,700° F., cooled slowly or quenched, and then reheated to from 1,450° to 1,500° F. and quenched. When the parts, in addition to being hard on the surface, must possess strength as well, they may be carburized at a temperature of from 1,650° to 1,700° F., cooled slowly in the carburizing mixture, reheated to from 1,500° to 1,550° F., quenched, reheated to from 1,400° to 1,450° F., quenched, and then drawn in oil at a temperature of from 300° to 450° F., depending on the degree of hardness desired. The object of heating the steel to a temperature of from 1,500° to 1,550° F. and quenching is to refine and strengthen the interior, or uncarburized, metal, and the object of reheating it to from 1,400° to 1,450° F. and quenching is to refine and harden the exterior, or carburized, metal. The drawing operation should last from 1 to 3 hours, the object of the operation being to relieve the internal stresses produced by quenching and to decrease the hardness somewhat.

52. .30 Carbon Steel.—The heat treatments usually given .30 carbon steel are those that will strengthen and toughen it. The simplest form of heat treatment suitable for this steel is to heat it to from 1,475° to 1,525° F., quench, and then reheat to from 600° to 1,200° F. and cool slowly. The object of reheating

to from 600° to 1,200° F. is to draw the temper, thereby relieving the internal stresses and reducing the hardness. If great toughness and little strength are desired, the higher drawing temperatures may be employed, while if much strength and little toughness are desired, the lower drawing temperatures should be used. Even when the lowest drawing temperature is used, the steel thus heat treated will be sufficiently tough for many important parts.

When extremely good qualities are required, together with a refinement of grain not possible with the single treatment just given, the steel may be heated to from 1,500° to 1,550° F., quenched, reheated to from 1,400° to 1,450° F., quenched, and then reheated to from 600° to 1,200° F. and cooled slowly.

Steel containing .30 per cent. of carbon may be case hardened, but only when the carburizing is followed by reheating to from 1,500° to 1,550° F., and quenching to refine the interior metal, and then by reheating to from 1,400° to 1,450° F. and quenching to refine the exterior metal. This last operation should be followed by drawing in oil at a temperature of from 300° to 450° F. As a rule, however, .30 carbon steel is only used for parts to be case hardened when .20 carbon steel is not available.

53. .40 Carbon and .50 Carbon Steels.—The uses of .40 carbon and .50 carbon steel are more limited than those containing less carbon, as they are only used for such parts that require a high strength and toughness. These steels are seldom employed for parts to be case hardened. They machine well when annealed, and their fatigue-resisting, or endurance, qualities may be made very high by heating to from 1,500° to 1,550° F., cooling slowly, reheating to from 1,400° to 1,450° F., quenching, reheating to from 600° to 1,200° F., and cooling slowly. When considerable toughness is desired, this last reheating operation should be conducted at the higher temperatures, and when considerable strength is desirable it should be conducted at the lower temperatures. The temperature suitable for a particular job is best found by trial.

ALLOY STEELS

54. In the development of steel manufacture, alloy steels have largely taken the place of carbon steels for parts that require great strength or toughness, a high elastic limit, or great fatigue-resisting qualities. Alloy steels should never be used in an annealed, or natural, state, but only in a heat-treated condition. When used in the natural condition, practically no advantage will be had over carbon steels; but when used in the heat-treated condition, there is a very marked improvement in the properties of the steels. The requirements of automobile manufacturers have in a large measure been responsible for the development of alloy steels and the heat treatments given them. These heat treatments have, from time to time, been reported to the Society of Automobile Engineers, acted on by the proper committee of the society, and published in their bulletins as recommended heat treatments. While intended primarily for the manufacturers of automobile parts, these treatments are, however, available to all who use alloy steels. The low-carbon alloy steels most commonly used are *nickel steel*, *nickel-chromium steel*, and *chromium-vanadium*, or *chrome-vanadium, steel*.

NICKEL STEEL

55. Nickel is a metal that in many of its properties is very similar to iron, and it seems to form a perfect alloy with iron in practically all proportions.

It has been alloyed with steels of almost all percentages of carbon, but its special use seems to be in low-carbon steel that contains between 3 and 4 per cent. of nickel.

Nickel steel is a very close-grained, tough material of great strength; like all steel, however, it requires careful treatment to obtain the best results. Its tensile strength and resistance to wear are remarkably high. It is more expensive than ordinary low-carbon steel; its greater cost is, however, not due to the nickel that it contains, but to the very large amount of extra work required to bring it to its best condition. Such

parts as crankpins for locomotives, gun barrels to be used with high-power explosives, piston rods and connecting-rods for high-speed engines, especially when of large size, and many other pieces, are made from nickel steel owing to its toughness and great strength. A good forging cannot, however, be made from a nickel-steel ingot by the ordinary forge and hammer used for low-carbon steel, without subsequent annealing, or heat, treatment. The heat treatment, which consists of annealing, oil tempering, and reannealing, brings out the good qualities of nickel steel.

It is claimed that 3 per cent. of nickel alloyed with an open-hearth steel containing .25 per cent. carbon produces a metal equal in tensile strength and ductility to a carbon steel of .45 per cent. carbon. By *ductility* is meant the amount the steel may be drawn out after it has been stretched beyond the point at which, when released, it will spring back to its original dimensions. By *elasticity*, or *resilience*, is meant that property of steel by which, after being stretched, it tends to return to its original size and shape. The influence of nickel on the elasticity and strength of steel increases with the percentage of carbon present, high-carbon nickel steels showing a greater increase than low-carbon steels.

56. .15-Per-Cent. Carbon, 3½-Per-Cent. Nickel Steel. The chief use of .15-per-cent. carbon, 3½-per-cent. nickel steel is for parts that are to be case hardened. The usual case-hardening treatment for this steel consists of carburizing at from 1,650° to 1,700° F., cooling slowly in the carburizing material, reheating to from 1,500° to 1,550° F., quenching, reheating to from 1,300° to 1,400° F., quenching, and then reheating to from 250° to 500° F. and cooling slowly. This last operation is to draw the temper and may be omitted; but when the parts are intricate in shape, having sudden changes of thickness or sharp corners, they should be drawn to relieve the internal stresses. When parts made of .15-per-cent. carbon, 3½-per-cent. nickel steel are given the foregoing heat treatment, they have an exceedingly strong and tough core and a high-carbon outer surface.

57. .20-Per-Cent. Carbon, $3\frac{1}{2}$-Per-Cent. Nickel Steel. The principal use of .20-per-cent. carbon, $3\frac{1}{2}$-per-cent. nickel steel is for parts that are to be case hardened, and the heat treatment suitable for these parts is that given in Art. **56.** This steel is also suitable for structural parts, and, when so used, the heat treatment consists of heating to from 1,500° to 1,550° F., quenching, reheating to from 1,300° to 1,400° F., quenching, reheating to from 600° to 1,200° F., and cooling slowly. The part of this treatment that consists of heating to from 1,300° to 1,400° F. is sometimes omitted, but when this is done the parts so treated are not so strong or tough, although they will give good service. The quenching medium used may be oil, water, or brine, the parts treated being toughest when quenched in oil and have a higher elastic limit when quenched in brine than when quenched in either oil or water. The degree of toughness and the elastic limit are also controlled by the amount the temper is drawn, the toughness being greatest when the parts are drawn to the higher temperatures and the elastic limit being higher when the parts are not drawn so much.

58. .30-Per-Cent. Carbon to .40-Per-Cent. Carbon, $3\frac{1}{2}$-Per-Cent. Nickel Steels.—Nickel steels containing $3\frac{1}{2}$ per cent. of nickel and from .30 to .40 per cent. of carbon are used for parts, such as axles, spindles, crank-shafts, driving shafts, transmission shafts, etc., and the heat treatment usually given these parts is that explained in Art. **57.** Parts made of .30-per-cent. carbon, $3\frac{1}{2}$-per-cent. nickel steel may be case hardened, but, as a rule, it is better to use steel containing less carbon for case-hardened parts. When the parts are to be case hardened, the treatment given in Art. **56** may be used. Greater hardness and brittleness are obtained in steel that contains .40 per cent. of carbon, and, consequently, the temper of the work should be finally drawn at a temperature of about 500° F., in order that the necessary degree of toughness may be obtained.

NICKEL-CHROMIUM STEEL

59. One effect of chromium in steel is to increase its hardening power. A steel rendered hard by the presence of chromium is, however, less brittle than one rendered hard by the presence of carbon. Hence, hardness combined with toughness may be secured by reducing the carbon and increasing the chromium content. The presence of both nickel and chromium in the steel makes it highly resilient and ductile, and gives it greater hardness and better wearing qualities than carbon steels. Nickel-chromium steels are especially valuable for parts to be hardened and tempered, as the fine structure produced has greater shock-resisting power than that of carbon steels. They have, however, the disadvantage of being difficult to forge and machine. The heat treatments and properties of these steels resemble those of nickel steels, but the presence of chromium serves to increase the effects of the heat treatments on the properties of the steel. These effects are further increased as the amounts of nickel and chromium in the steel are increased.

60. Nickel-chromium steels may be divided into four groups, according to the amount of nickel and chromium contained in them; namely, steels containing 1.25 per cent. of nickel and .60 per cent. of chromium, steels containing 1.75 per cent. of nickel and 1.10 per cent. of chromium, steels containing 3.00 per cent. of nickel and .80 per cent. of chromium, and steels containing 3.50 per cent. of nickel and 1.50 per cent. of chromium. These groups may be divided into subgroups according to the amount of carbon contained, as will be explained later.

61. 1.25-Per-Cent. Nickel, .60-Per-Cent. Chromium Steels.—Although it is desired that 1.25-per-cent. nickel, .60-per-cent. chromium steels contain 1.25 per cent. of nickel and .60 per cent. of chromium, yet, in this group, the nickel may vary from 1 to 1.5 per cent. and the chromium from .45 to .75 per cent. This group of steels may be further subdivided into those that contain .20, .25, .30, .35, and .40 per cent. of carbon.

62. .20-per-cent. carbon, 1.25-per-cent. nickel, .60-per-cent. chromium steel may contain from .15 to .25 per cent. of carbon, but preferably .20 per cent. This grade of steel is used chiefly for parts that are to be case hardened, and the usual treatment consists of carburizing at a temperature of from 1,650° to 1,700° F., cooling slowly in the carburizing material, reheating to from 1,500° to 1,550° F., quenching, reheating to from 1,300° to 1,400° F., quenching, and then reheating to from 250° to 500° F. and cooling slowly. Although used principally for case-hardened parts, the .20 per-cent carbon steel of this group is sometimes employed for other parts, but is never used without being heat treated. The heat treatments then employed are the same as those used for the steels in this group that contain larger amounts of carbon.

63. .25-per-cent. to .40-per-cent carbon, 1.25-per-cent. nickel, .60-per-cent. chromium steels are intended to be used for heat-treated parts that are not case hardened. The steels high in carbon are used for gears and other parts that must be very strong and hard, and need not be exceedingly tough, while those low in carbon are used where toughness is the first consideration. The usual heat treatment after the forging or machining is finished consists of heating to from 1,500° to 1,550° F., quenching, reheating to from 1,300° to 1,400° F., quenching, and reheating to from 600° to 1,200° F. and cooling slowly. The part of this treatment that consists of heating to from 1,300° to 1,400° F. and quenching is sometimes omitted, but when this is done, the properties of the steel are not so pronounced. The final reheating temperature varies from 600° to 1,200° F., the higher temperatures being used when toughness is of first importance and the lower temperatures when a high elastic limit is of the first importance. The quenching may be done in oil, water, or brine, the effect of quenching in brine being to produce a higher elastic limit but not as tough a part as would be had by quenching in either oil or water.

64. 1.75-Per-Cent. Nickel, 1.10-Per-Cent. Chromium Steels.—In the group known as 1.75-per-cent. nickel, 1.10-per-cent. chromium steels, the nickel may vary from 1.50

to 2.00 per cent., and the chromium from .90 to 1.25 per cent., although it is desired to have about 1.75 per cent. of nickel and 1.10 per cent. of chromium in these steels. This group may be divided into subgroups containing .20, .30, .40, and .50 per cent. of carbon.

65. Steels containing **.20-per-cent. carbon, 1.75-per-cent. nickel,** and **1.10-per-cent. chromium** are used principally for parts that are to be case hardened. While it is usually desirable to have the carbon content in a steel used for case-hardened parts to be about .20 per cent., yet it may vary from .15 to .25 per cent. The heat treatment suitable for this grade of steel consists of carburizing at a temperature of from 1,600° to 1,750° F., cooling slowly in the carburizing material, reheating to from 1,450° to 1,525° F., quenching, reheating to from 1,300° to 1,400° F., quenching, drawing the temper in a bath at from 250° to 500° F., in accordance with the degree of toughness required, and cooling slowly.

66. The **.30-per-cent. carbon, 1.75-per-cent. nickel, 1.10-per-cent. chromium steel** is intended for parts that are not to be case hardened. This steel resembles the .30-per-cent. carbon, $3\frac{1}{2}$-per-cent., nickel steel except that, owing to the presence of chromium, the effect of heat treatment on it is more pronounced. The usual treatment consists of heating the steel, after it has been forged or machined, to from 1,475° to 1,525° F., quenching, reheating to from 500° to 1,200° F., and cooling slowly. This steel may also be used for parts that are to be case hardened, but, as a rule, it is better to use steel that contains less carbon for this class of work. When it is desired to case harden this steel, the treatment given in the preceding article is used.

67. The **.40-per-cent. carbon, 1.75-per-cent. nickel, 1.10-per-cent. chromium steel** is used for automobile or other parts when a fairly high degree of strength and hardness combined with considerable toughness is required. This steel is never used for parts that are to be case hardened, and it is always employed in the heat-treated condition. The usual treatment consists of heating the steel, after it has been forged or machined,

to a temperature of from 1,475° to 1,525° F., quenching, reheating to from 1,350° to 1,400° F., quenching, reheating to from 600° to 1,200° F., and cooling slowly. The last reheating operation is done to reduce the hardness of the steel and to render it tougher, the higher temperatures being used when toughness is the first consideration and the lower temperatures when a high elastic limit is of the first importance.

68. The **.50-per-cent. carbon, 1.75-per-cent. nickel, 1.10-per-cent. chromium steel** is used for such parts as oil-hardened gears and springs, and a variety of automobile parts. It is almost always quenched in oil when heat treated, although, when an exceedingly high elastic limit is desired at a sacrifice of toughness, the steel may be quenched in water. The usual treatment consists of heating the part, after it has been forged, to a temperature of from 1,475° to 1,525° F., and holding it at this temperature for about $\frac{1}{2}$ hour to insure thorough heating, cooling slowly, reheating to from 1,400° to 1,450° F., quenching, reheating to from 300° to 600° F., and cooling slowly. This steel is hard to machine, and it is necessary that the steel be carefully annealed before machining. The annealing is done by heating it to from 1,475° to 1,525° F. and cooling it slowly.

69. 3.00-Per-Cent. Nickel, .80-Per-Cent. Chromium Steels.—In 3.00-per-cent. nickel, .80-per-cent. chromium steels, the nickel may vary from 2.75 to 3.25 per cent. and the chromium may vary from .60 to .95 per cent. This group of steels may be subdivided into steels containing .15, .35, and .50 per cent. of carbon. All the steels of this group must be annealed before they can be machined. The annealing is done by heating the steel to a temperature of from 1,450° to 1,500° F., and cooling it slowly.

70. The **.15-per-cent. carbon, 3.00-per-cent. nickel, .80-per-cent. chromium steel** may contain from .10 to .20 per cent. of carbon, although it is desired to have about .15 per cent. This steel is used almost entirely for case-hardened parts, although it is sometimes used for parts that are not case hardened. The usual heat treatment for this steel after it has been forged or machined, consists of carburizing the outer surface

at a temperature of from 1,650° to 1,750° F., preferably from 1,650° to 1,700° F. It is next cooled slowly in the carburizing material, after which it is reheated to a temperature of from 1,400° to 1,500° F., and quenched. It is then reheated to a temperature of from 1,300° to 1,400° F., and quenched, after which it is reheated to a temperature of from 250° to 500° F., to reduce the hardness and relieve the internal stresses, and then cooled slowly. When used for parts that are not to be case hardened, one of the heat treatments given in the following article for .35-per-cent. carbon steel of this group may be employed.

71. The **.35-per-cent. carbon, 3.00-per-cent. nickel, .80-per-cent. chromium steel** is used for parts that must be very strong and tough, and have a high fatigue-resisting capacity. This steel is suitable for crank-shafts, axles, spindles, drive and transmission shafts, and other important parts of automobiles. It is not used for parts that are to be case hardened, and is never employed without being heat treated. A satisfactory heat treatment for this steel consists of heating it, after it has been forged or machined, to a temperature of from 1,400° to 1,500° F., and then quenching in oil or water, depending on the degree of toughness and the elastic limit required. The work is then reheated to a temperature of from 500° to 1,250° F., and allowed to cool slowly.

72. The **.50-per-cent. carbon, 3.00-per-cent. nickel, .80-per-cent. chromium steel** is used where extreme strength and hardness is required. It is used largely for gears, as they are sufficiently hard when properly heat treated without being case hardened. The usual heat treatment for parts made of this steel consists of heating the work, after it has been forged, to a temperature of from 1,475° to 1,525° F., holding it at this temperature for ½ hour to insure thorough heating. The work is then cooled slowly and machined. It is afterwards reheated to a temperature of from 1,450° to 1,500° F., and quenched in oil, after which it is reheated to from 250° to 550° F., and allowed to cool slowly. This last reheating is done to reduce the hardness a little, and is conducted at that temperature which will produce the desired hardness as found by experience.

73. 3.50-Per-Cent. Nickel, 1.50-Per-Cent. Chromium Steels.—In 3.50-per-cent. nickel, 1.50-per-cent. chromium steels, the nickel may vary from 3.25 to 3.75 per cent. and the chromium may vary from 1.25 to 1.75 per cent. This group of steels may be subdivided into steels containing .20 per cent. and .40 per cent. of carbon. Both of the latter groups must be annealed before they can be machined. The annealing is done by heating the steel to a temperature of from 1,450° to 1,500° F., and cooling it slowly.

74. The **.20-per-cent. carbon, 3.50-per-cent. nickel, 1.50-per-cent. chromium steel** may contain from .15 to .25 per cent. of carbon. The steel is used principally for parts that are to be case hardened. The usual treatment consists of carburizing the work, after it has been forged or machined, at a temperature of from 1,600° to 1,750° F., 1,650° to 1,700° F. being preferred, and then cooling slowly in the carburizing mixture. The work is then reheated to a temperature of from 1,400° to 1,500° F. and quenched, after which it is reheated to from 1,300° to 1,400° F., and again quenched. It is next reheated to from 250° to 500° F., and allowed to cool slowly. This grade of steel may also be used for other than case-hardening purposes when properly heat treated. When so used, the heat treatment that is generally employed consists of heating the work, after it has been forged or machined, to a temperature of from 1,375° to 1,425° F., quenching, reheating to from 500° to 1,250° F., and cooling slowly. The exact range of temperature and the quenching medium used must be determined by experiment. They depend on the degree of toughness, strength, hardness, and elastic limit required.

75. The **.40-per-cent. carbon, 3.50-per-cent. nickel, 1.50-per-cent. chromium steel** is suitable for parts that must be unusually strong. This steel is not as tough as those that have been mentioned previously, but, when properly heat treated, its elastic limit can be made higher than any of the others. Parts made of it should not be case hardened, and must be thoroughly annealed before they can be machined. The usual heat treatment consists of heating the work, after it has been

forged or machined, to a temperature of from 1,450° to 1,500° F., and quenching. The work is then reheated to from 1,375° to 1,425° F., and quenched, after which it is reheated to a temperature of from 500° to 1,250° F., and cooled slowly. The exact range of temperature and the quenching medium used depend on the degree of strength, toughness, and elastic limit required.

CHROMIUM-VANADIUM STEELS

76. Vanadium is often added to steel in quantities up to .5 per cent. Its effect is to intensify, or make more evident, the properties of other constituents of the steel, and to render it highly ductile and resilient. Chromium-vanadium steels usually contain from .70 to 1.10 per cent. of chromium and not less than .12 per cent. of vanadium, .90 per cent. of chromium and .18 per cent. of vanadium being desired. They are used for much the same purposes as are nickel-chromium steels, and their properties are very similar, except that, owing to the presence of vanadium, they are intensified. Chromium-vanadium steels are easier to forge and machine than nickel-chromium steels.

77. .20-per-cent. Carbon, .90-Per-Cent. Chromium, .18-Per-Cent. Vanadium Steel.—The .20-per-cent. carbon, .90-per-cent. chromium, .18-per-cent. vanadium steel may contain from .15 to .25 per cent. of carbon, although .20 per cent. is generally preferred. This steel is used for parts that are to be case hardened and that require an extremely high degree of strength and toughness. The usual heat treatment consists of carburizing at a temperature of from 1,600° to 1,750° F., 1,650° to 1,700° F. being preferred, and then cooling slowly in the carburizing mixture. The work is then reheated to from 1,600° to 1,700° F. and quenched, after which it is heated again to from 1,475° to 1,550° F. and quenched. This last reheating operation should be conducted at the lowest temperature that will harden the carburized surface, as determined by trial. The work is next reheated to from 250° to 550° F., the temperature depending on the hardness and toughness required, and cooled slowly.

When used for other than case-hardened parts, the heat treatment given in the following article should be used.

78. .25- to .40-Per-Cent. Carbon, .90-Per-Cent. Chromium, .18-Per-Cent. Vanadium Steels.—The .25- to .40-per-cent.carbon, .90-per-cent. chromium, .18-per-cent. vanadium steels are used for such parts as axles, shafts, and steering knuckles of automobiles. The .30-per-cent. carbon steel possesses a high degree of combined strength and toughness, the .35-per-cent. carbon steel has high fatigue-resisting, or endurance, qualities, and the .40-per-cent. carbon steel is used where great strength is desired, coupled with a good measure of toughness. The fatigue-resisting qualities of the .40-per-cent. carbon steel are high. This steel is excellent for shafts that must withstand heavy stresses. None of these steels are used without being heat treated. The usual heat treatment consists of heating the work, after it has been forged or machined, to a temperature of from 1,600° to 1,700° F., and quenching, following which it is reheated to a temperature of from 500° to 1,300° F., and cooled slowly. The quenching medium and the exact range of temperature used depend on the hardness, toughness, and elasticity required.

79. .45- to .50-Per-Cent. Carbon, .90-Per-Cent. Chromium, .18-Per-Cent. Vanadium Steels.—The .45- to .50-per-cent. carbon, .90-per-cent. chromium, .18-per-cent. vanadium steels contain enough carbon, in combination with the chromium and vanadium, to be hardened when heated to the proper temperature and quenched. They are used for gears and springs, and when properly heat treated have very high elastic limits. When used for gears, the steel should be annealed after forging and before machining. The annealing is done by heating the steel to a temperature of from 1,525° to 1,600° F., holding it at this heat for about 1 hour, and cooling slowly. Usually, after the annealing and machining are finished, the work is reheated to a temperature of from 1,650° to 1,700° F., quenched, reheated to from 350° to 550° F., and cooled slowly. When used for springs, this last reheating operation should be at a temperature of from 700° to 1,100° F.

COLORING OF STEELS

COLORING BY TEMPERING

80. To produce temper colors on hardened or case-hardened work, the pieces are first hardened or case hardened and then rolled in a tumbling barrel with leather scraps or other polishing material until the surface is polished to the desired degree; the pieces may then be heated in a sand bath or in a tumbling-barrel furnace to draw the temper until the desired color appears. The work is then plunged into cold water, dried in sawdust, and oiled slightly to avoid tarnishing. By doing the work in a gas-fired tumbling-barrel furnace or in a gas-fired air-tempering furnace and noting the exact time required, the desired color can be obtained with great exactness, it being an easy matter to produce any color from a light straw to a deep blue. The blue pieces will be somewhat softer than the straw-colored ones. Sometimes the pieces are placed in a revolving wire cylinder over a slow fire; this permits the color of the work to be observed at any time. The fire used for heating the work must, of course, be free from sulphur or anything that will give off gases that will stain the work.

81. Steel articles may be blued by heating them in hot sand. They can also be blued by placing them in sheet-iron boxes suspended in a furnace in such a way that they can be tilted from side to side, so as to cause the articles to move or slide about. In either case, the operator watches the articles until the desired color is obtained, when the work is quickly removed and allowed to cool in the air. With care, very beautiful colors may be produced in this manner. A sand-drawing furnace arranged to shower hot sand over the work may also be used for bluing steel.

COLORING TO RESIST RUST

82. It is frequently desirable to produce on steel a blued surface that is not only ornamental, but that resists rust. One method of doing this work is as follows: A cast-iron pot of sufficient size is set in the top of a brick furnace and heated with a hard coal or coke fire beneath it, or with a gas or oil flame. The pot is nearly filled with a mixture of ten parts of niter and one part of black oxide of manganese, which is maintained at a temperature just below a black heat, the temperature being gauged by occasionally throwing a little fine sawdust on the surface of the molten mixture. When the temperature is right, the sawdust will take fire in a few seconds, but will not flash into fire instantly. The manganese does not melt, and the mixture must be stirred with an iron rod just before dipping the work for bluing.

The pieces of work are placed in a wire basket and lowered into the the hot mixture; the basket is moved up and down in the mixture a little to observe the color, which should be right for small work in from 1 to 2 minutes. As soon as the desired color is obtained, the basket with its contents is lowered into a tank containing a hot solution of soda, in which it is moved up and down several times. It is then transferred to a tank of clear, boiling water, again moved up and down to wash it thoroughly, and lifted from the water, when the heat in the work will dry it quickly.